The AMERICAN PHYSICS TEACHER

VOLUME 5 FEBRUARY, 1937 NUMBER 1

Models to Illustrate Gyromagnetic and Electron-Inertia Effects*

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IN a recent number of this journal Professor Webster[1] has advocated the idea that elementary instruction in magnetism should be based primarily on Ampère's conception of molecular whirls and my own experiments on magnetization by rotation, rather than on magnetic poles and Coulomb's law. Although these experiments were first made and described over twenty years ago,[2] most teachers of elementary physics in this country seem entirely unacquainted with them; and only a few of our elementary textbooks on physics, such as those of Crew, Webster, Farwell and Drew, Loeb and Adams, and Saunders, mention them.

As to the desirability of introducing this material in elementary courses on electricity and magnetism, I agree fully with Professor Webster. The importance of the work is due to the following five facts: (1) It has revealed a second and entirely new method of magnetizing bodies, the only previously known method consisting of placing them in a magnetic field; (2) It has given the first proof of the actual existence of Ampère's molecular currents; (3) It has shown that the electricity involved in these currents is negative; (4) From the magnitudes of the observed quantities, it has shown that the chief role in ferromagnetism is taken by the spinning Lorentz electron as magnetic element; and (5) It has thus furnished a basis for new and more nearly ultimate theories of magnetism.

For many years I have described and explained these experiments to my own classes with the aid of gyroscopic models and lantern slides, and the students have never failed to show the greatest interest in them. The object of this paper is to describe some of the models which have been used to illustrate this subject and that of the converse effect, rotation by magnetization, as well as models to illustrate the closely related subject of electron-inertia in metallic conduction—which also, in my opinion, should always be taken up with elementary classes in electricity.[3]

GYROMAGNETIC MODELS

The first model to be described is one which I have used for many years, and repeatedly described, and which is illustrated in Fig. 1. This figure represents a slight modification of a common type of gyroscope. The wheel, pivoted in a light frame, can be rotated rapidly about its

* A paper presented in part to the American Physical Society at the Seattle meeting, June, 1936.

[1] Am. Phys. Teacher **2**, 179 (1934).

[2] S. J. Barnett, Phys. Rev. **6**, 239 (1915).

[3] For a general account of all the work done on these phenomena, see S. J. Barnett, "Gyromagnetic and Electron-inertia Effects," Rev. Mod. Phys. **7**, 129–66 (1935). For recent, briefer reviews of the work on gyromagnetic phenomena, see S. J. Barnett, Physica **8**, 241–68 (1933) and O. von Auwers, Naturwiss. **23**, 202–10 (1935). A semi-popular account of the work on gyromagnetic phenomena up to 1930 is given in S. J. Barnett, *Evidence on the Nature of the Elementary Magnet from Researches on Gyromagnetic Phenomena* (Univ. of Calif. Printing Office, 1930), pp. 1–43. For a brief historical account of gyromagnetic effects see S. J. Barnett, Physik. Zeits. **35**, 203–5 (1934). Brief but excellent discussions of the phenomena are given in Crew, *The Rise of Modern Physics* (ed. 2, 1935), pp. 321–330, and Stoner, *Magnetism and Matter* (1934), Chap. VIII.

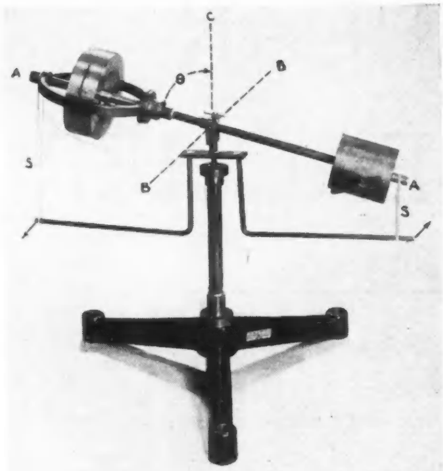

FIG. 1. Model to illustrate magnetization by rotation.

axis A; that is, it can be given *angular momentum* about A. Except for the action of two small springs or rubber bands SS, this frame and the axis A are free to move in altitude about a horizontal axis B, perpendicular to A; and the axis B and the whole instrument can be rotated about a vertical axis C. If the wheel's speed about the axis A is zero, no tip occurs when the whole instrument is rotated about the axis C. But if the wheel is spun about A, and thus given angular momentum about this axis, and the instrument then is rotated about C, the wheel tips up or down so as to make the direction of its spin coincide more nearly with the direction of the impressed rotation about C. The greater the speed about the vertical the greater is the tip of the wheel. If it were not for the springs or bands SS, and the mechanical obstructions due to the form of the instrument, the wheel would tip until the axes A and C became coincident. It is quite unnecessary for the present purpose to show the student why a gyroscope behaves in this way. The facts are entirely sufficient for what follows.

Now, as every one knows, according to Ampère's hypothesis each of the elementary magnets of which a magnetic body is, at least in part, built up, is constituted of a minute electrical whirl. And if the electricity which is revolving or spinning in this whirl is endowed with mass, each whirl, which constitutes an elementary magnet, must also have angular momentum, and thus exhibit the mechanical properties of our gyroscope wheel.

Since the magnetic axis of every whirl bears the same relation to its rotary motion or momentum, an unmagnetized rod, in which the axes of the whirls point in all directions equally, will have no resultant momentum about any direction, just as it has no resultant magnetic moment. If the rod is magnetized to saturation, however, the magnetic axes of all the whirls point in the same direction, and thus the rod will have a resultant angular momentum equal to the sum of the angular momenta of all its whirls, and should exhibit the properties of a spinning top or gyroscope.

If, therefore, from our apparatus we remove the wheel and replace its axle by a highly magnetized rod of iron, and then rotate the framework about the vertical, as before, the axis of the rod should tip up or down according to the direction of rotation about the vertical—provided extraneous disturbances are not too great to mask the effect.

Essentially this experiment was tried by Maxwell[4] in or before 1861, though with quite different apparatus. No appreciable effect was observed, undoubtedly because the extraneous disturbances due to the earth's magnetic field and the mechanical imperfections of the apparatus were too great, and the method of observation too insensitive.

Maxwell's experiment was an experiment on the angular momentum of a gross magnet. In the experiments on magnetization by rotation every one of the countless multitude of elementary magnets in the magnetic body rotated simultaneously replaces his magnet, and the total change in the orientation of all the elementary magnets is measured by means of the change of magnetization produced by the body's rotation.

The qualitative theory of the phenomenon with which these experiments are concerned is thus as follows: When a magnetic substance is set into rotation about any axis, each elementary magnet, since it has angular momentum, must behave like the wheel of our gyroscope, and change its orientation in such a way as to make

[4] *Treatise on Electricity and Magnetism*, ed. 3, §575.

the direction of revolution of its electricity coincide more nearly with the direction of this impressed rotation.

Only a slight change of orientation can occur on account of the torques due to adjacent elementary particles, which perform the restraining function of the springs in the experiment with the gyroscope. The rotation thus causes every element to contribute a minute angular momentum in the same direction around the axis of rotation and thus also a minute magnetic moment parallel to the axis of rotation; and thus the body, whose molecular magnets originally pointed in all directions equally, becomes magnetized along the axis of rotation.

If the wheels are all constituted of positive electricity, the body will become magnetized in the direction in which it would be magnetized by an electric current flowing around it in the direction of the angular velocity imparted to it. If the wheels are all constituted of negative electricity, or if the effect of the negative electricity is preponderant, it will be magnetized in the opposite direction. The latter is what actually happens.

Several years ago, at the request of Professor Henry Crew, then Director of Exhibits in the Mathematical Sciences at the exposition *A Century of Progress*, I designed and had constructed, primarily for use at the exposition, an automatic model (Fig. 2) which is still more interesting and instructive than the model just described. A rigid metal framework, mounted in ball bearings on a heavy tripod, is rotated at will about a vertical axis by means of a small (1/50-hp) electric motor A, to whose shaft it is connected by a worm-and-wheel gear. The frame carries two very small (1/100-hp) and exactly similar electric motors B and B', one vertically above the other. These motors are symmetrically mounted in the frame on short horizontal rods with ball bearings in such a way that they can rotate with reference to the frame only about parallel horizontal lines perpendicular to their own armature axes and passing through their centers of mass. Two flat spiral springs, inclosed in housings at the ends of the rods passing through the bearings, and provided with convenient means of adjusting their tensions, keep the armature axis of each motor horizontal unless

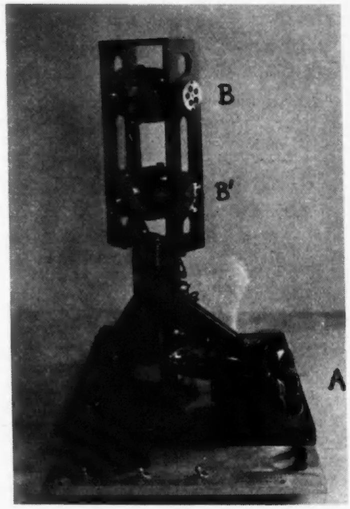

FIG. 2. Automatic model to illustrate magnetization by rotation.

the armature of the motor is in rotation about its own axis and the frame is simultaneously in rotation about the vertical. The springs resist the motion of the motor axes in altitude.

All the motors are series wound and driven by 110-volt direct or alternating current. Slip rings and brushes are of course provided for the motors B and B'.

Each of these motors carries similar (and relatively heavy) brass flywheels at the two ends of its armature axle, that at one end being painted red on the rim, and that at the other, white. The two motors rotate at the same (fixed) speed, and in opposite directions when their axles are horizontal. Arrows on the faces of the flywheels indicate these directions. To one looking at the face of a red flywheel the rotation is anticlockwise; so that if we think of the wheels as consisting of positive charges in revolution or rotation, each rotor represents an Ampèreian whirl with its axis directed from the white to the red wheel, or an elementary magnet with the red end a positive pole and the white end a negative pole. If we think of the rotors as consisting of negative charges in motion, the axes and polarities are of course reversed.

Four switches are provided for controlling the electric circuits: No. 1 opens or closes the circuit

of motor A; No. 2 inserts a resistor (lamp) in this circuit, or cuts it out, at will, thus decreasing or increasing the speed of A; No. 3 opens or closes the circuits of motors B and B', which are connected in parallel; No. 4 reverses the field of motor A to change the direction of its rotation.

(1) The frame is rotated at low speed with no current in the motors B and B', whose axes remain horizontal. They are not rotating about their own axes and represent a non-magnetic body. The frame only entrains them in its motion. Increasing the speed of motor A leaves the axes still horizontal.

(2) Motor A is now stopped. Motors B and B' are then set into rotation, and spin in opposite directions, but remain with their axes horizontal. In this state they represent a *magnetic*, but *unmagnetized* body. If now, by the motor A, the frame is set into rotation at low speed in the anticlockwise direction to one looking down upon it, the axes of B and B' change their altitudes, and soon exhibit "regular" precession, each keeping a constant angle with the vertical. The spin of each rotor may now be thought of as partly about a vertical axis and partly about a horizontal axis. The spins about the vertical are just alike for the two rotors, and *in the same direction* as the rotation of the frame; the spins about the horizontal are *opposite* for the two rotors. The red ends of both rotors are displaced *upward* (and the white ends downward) equally, while the *oppositely* colored ends of the two rotors are displaced laterally in the same direction and equally. When a vertical bar of iron is rotated like the model, each of the countless multitude of elementary magnets which it contains will behave much like the rotors of the model. The result is that the bar will become magnetized upward (positive pole above, negative pole below) or downward (negative pole above, positive pole below), according as the electricity in the spinning elements is positive or negative. The bar will remain unmagnetized laterally. As a matter of fact, it is found to be magnetized *downward*, the result proving that the whirling electricity is *negative*.

(3) If now the motion of the frame is reversed, the red ends of the rotors will tip downward instead of upward. Again the spins about the vertical will be like that of the frame, and the spins about the horizontal will again be opposite. In the magnetic case, the rod will be magnetized in the direction opposite to that in which it was magnetized before.

FIG. 3. Model to illustrate magnetization by rotation and its converse. Unmagnetized state of magnetic substance.

(4) If now the frame is rotated faster the axes of the rotors will become more nearly vertical. The rod in the analogous case will be more highly magnetized.

In this case and the preceding cases the rotors would turn until their axes were completely vertical except for the restraining force actions of the springs. And in the magnetic case, every elementary magnet would turn until its axis was vertical, the rod thus being magnetized to saturation, except for the restraining force-actions due to the adjacent elements.

The model just described was exhibited at the exposition *A Century of Progress* during both its sessions; and between these sessions it was exhibited at the New York Museum of Science and Industry at the request of the director. For the purpose of public exhibition it was provided by the Chicago exposition with a

FIG. 4. Model to illustrate magnetization by rotation and its converse. Magnetized state of magnetic substance.

motor-driven switching device which made the operation entirely automatic on the pushing of a single button.

Another model which I have used for a long time and which operates much like the automatic model just described, and is capable of doing still more, is illustrated in Figs. 3 and 4. It is a semi-human model. A pair of automobile roller bearings is mounted on the floor with the axis vertical. One bearing is fixed in a framework which rests on the floor. To the other is attached a small horizontal platform, on which a student can stand or can sit on a stool. This apparatus is of course well known.

The student, at rest, holds in his hands the axles of two bicycle wheels, symmetrical and coaxial (Fig. 3). The wheels, imagined to be electrically charged, are initially at rest. Neither wheel has either magnetic moment or angular momentum.

The wheels are now given equal speeds in opposite directions. Each wheel is now a magnet and has angular momentum; but the whole body—the substance now become magnetic—is unmagnetized and without angular momentum, because the axes of the two elementary magnets are opposed.

The stool is now rotated. The wheels turn and strive to take up the positions of Fig. 4, in which they are rotating in the same direction, namely, that of the rotation impressed on the stool. The body is now magnetized, and has angular momentum. If now the motion is stopped, the wheels return to their original orientations and positions and the total magnetic moment and the total momentum disappear together. If the motion is reversed, the wheels turn in the opposite directions.

The same apparatus may be used to illustrate the converse of my own experiments—the production of rotation by magnetization.[5] We may start as before with the wheels parallel and spinning in opposite directions, so that the body is magnetic, but is unmagnetized and without angular momentum. If now the student bends his arms from the positions in Fig. 3 to those of Fig. 4, he, the stool, and the wheels all rotate together in the opposite direction about the vertical to the (now) common direction of spin of the wheels. The body is now magnetized, and the student, etc., have received an angular momentum equal in magnitude, but opposite in direction, to the sum of the separate spin momentums of the two wheels.

In the actual magnetic experiment, first performed successfully by Einstein and de Haas,[5] a vertical magnetic rod is hung on an elastic suspension, and vertically magnetized. The Ampèreian whirls are lined up in the same direction, and the whole rod receives an angular momentum equal in magnitude and opposite in direction to the combined momenta of all the individual molecular whirls. When the rod is demagnetized it receives an angular impulse in the opposite direction; and when the student turns the wheels down until their axes are again horizontal and their rotations opposite, he comes to rest. If the torsion of the suspension were negligible, the rod in the first part of the magnetic experiments would of course go on rotating indefinitely, and in the second part would come to rest.

[5] A. Einstein and W. J. de Haas, Verh. d. D. Phys. Ges. **17**, 152 (1915); A. Einstein, ibid. **18**, 173 (1916); W. J. de Haas, ibid. **18**, 423 (1916); and the references given in footnote 3. This experiment was first suggested by O. W. Richardson, Phys. Rev. **26**, 248 (1908).

Electron-Inertia Models

Maxwell, in his *Treatise*,[6] describes three inertia effects which should exist in conductors if the electric current is due to the motion of one kind of electricity only, and if this electricity has inertia.

(1) If a circular coil of wire is traversed by a steady electric current the electricity has a constant angular momentum about the axis, so that the coil, like a magnet, or a magnetic element, should exhibit the properties of a gyroscope. Maxwell tried this experiment in connection with his gyromagnetic experiment already referred to. In fact, his magnet was an electromagnet from which the iron core could be removed at will. When it was removed, the experiment was one on the inertia of electrons in copper. But for the reasons already given no effect was observed. Any one of the models previously described will suffice to illustrate this effect.

(2) If the coil of wire is accelerated about its axis, the free electricity will be differently accelerated, lagging behind when the coil's speed is increased, and going ahead when the speed is decreased. Thus the acceleration of the coil gives rise to an electric current in it. This is the effect described by R. C. Tolman and T. D. Stewart[7] in 1916.

Fig. 5. Model to illustrate electron-inertia effects.

It can be illustrated with the arrangement of Fig. 5, which is the same as that of Figs. 3 and 4, except that only one wheel is necessary. We may suppose the student and the stool to represent the coil, and the wheel to represent the mobile electricity in the coil. Initially the wheel, with its axis vertical, and the student are both at rest. If now the stool, with the student, is rotated about the vertical, the wheel will only gradually pick up his motion; an electric current exists until, on account of friction, they both come to rotate together with the same speed. If the student clasps the wheel and the experimenter rotates them and the stool together at the same speed, and if then the student releases the wheel and the experimenter brings the stool to rest, the wheel goes on rotating until friction brings it to rest; an electric current exists until resistance dissipates all the energy. If the student gives the wheel an oscillatory motion about the vertical, he will himself oscillate, always in the opposite phase. The oscillation of a closed electric coil about its axis thus produces an alternating current in the coil.

(3) Another electron-inertia effect, the converse of (2), is as follows: If a current in a circular coil of wire free to move about its axis is started or stopped or altered, the free electricity will be accelerated, and the coil itself will be accelerated in the opposite direction. This effect was found by the author[8] in 1930. The student, on the stool, gives the wheel, with vertical axis, a rotation. He and the stool rotate in the opposite direction. He brings the wheel to rest, and simultaneously comes to rest himself. If he oscillates the wheel, he and the stool oscillate in the opposite phase.

For the construction of the automatic model described here I am indebted to Mr. G. H. Jung of the University of California, whose work was so good that the model was reported by the authorities of the Chicago exposition to have been exhibited to thousands of visitors without ever getting out of order. For the figures I am under obligations to Mr. L. H. Humason of the University of California, and to Messrs. J. H. Munier and R. Watson, now of Johns Hopkins University and Harvard University, respectively.

[6] Reference 4, §§574, 575, 577.
[7] Phys. Rev. **8**, 97 (1916).
[8] Phil. Mag. **42**, 349 (1931).

The Principles Involved in Determining the Absolute Values of the Electrical Units*

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THE electrical units in common use, namely, the ohm, ampere, volt, etc., were derived from the magnetic effects of an electric current and from the requirement that the units of energy and power in the electrical system should be the same as in the cgs mechanical system. The decision to adopt these principles as the basis of a system was made in 1863 by a committee of the British Association for the Advancement of Science, after consultation with the principal physicists in the world. This decision was confirmed by an International Electrical Congress meeting in Paris in 1881, and the system of units established at that time is now universally used. However, the units have become so common that many students overlook the principles which were employed to establish them. In this paper an attempt is made to state these principles in such a manner that they will be readily appreciated by the students in undergraduate courses of physics.

MAGNETIC UNITS

The units of the electromagnetic system are based on magnetic phenomena so that certain magnetic units need to be defined before starting on the electrical definitions.

A common method of developing the definitions of the magnetic quantities is to begin with *pole strength*, which is defined in the cgsm system as numerically equal to the force in dynes between two poles which are equal in magnitude when at a distance of 1 cm in a vacuum. In this definition it is assumed that the poles are concentrated at points. If there is a medium surrounding the poles, the force will be different from that when they are in a vacuum. The ratio of the force in the medium to the force in a vacuum is the *permeability* of the medium.

The *magnetic intensity* in oersteds at any point in the neighborhood of a magnetic pole which is concentrated at a point is numerically equal to the quotient obtained by dividing the pole strength by the square of the distance in centimeters between the point and the pole. The *magnetic induction* in gausses at any point in a homogeneous, isotropic region surrounding a magnetic pole is the product of the permeability of the medium and the magnetic intensity. Only these magnetic definitions are required in connection with the definition of the electrical units.

* Publication Approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

CURRENT

Current is generally taken as the first electrical quantity with which to connect the electromagnetic system of units to the mechanical system. The definition for unit current in the cgs electromagnetic system is not the same in all texts, but the most common one is that the current in a conductor 1 cm long which is bent in an arc of a circle of 1 cm radius, has a value of unity when a unit magnetic pole placed at the center of the arc is acted upon with a force of one dyne. This definition, which assumes that the apparatus is in a vacuum, is illustrated in Fig. 1(a), where the point placed at the center of the arc of the conductor in which there is a current I, represents a magnetic pole of strength m. The magnitude of the force F on the magnetic pole, in a direction perpendicular to the paper, is given by the equation

$$F = mI. \tag{1}$$

Since, by Newton's law of action and reaction, the force on the conductor must be equal in magnitude and in the opposite direction to the force on the magnetic pole, an equally precise definition can be made by defining the current in terms of the force on the conductor. With unit pole at the center of the arc, the magnetic induction at each point of the conductor is 1 gauss and is perpendicular to the conductor at every point of its length. Hence, the equivalent

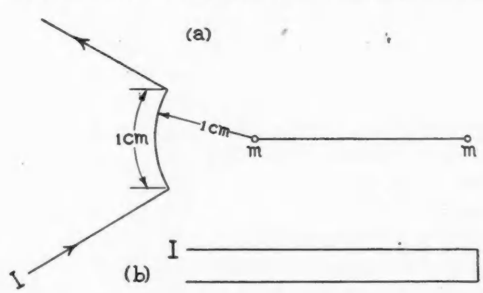

FIG. 1. Circuits used in defining the absolute value of a current. In (a) the two poles of a magnet are indicated, but the definition of current involves only the force on the pole at the center of the arc.

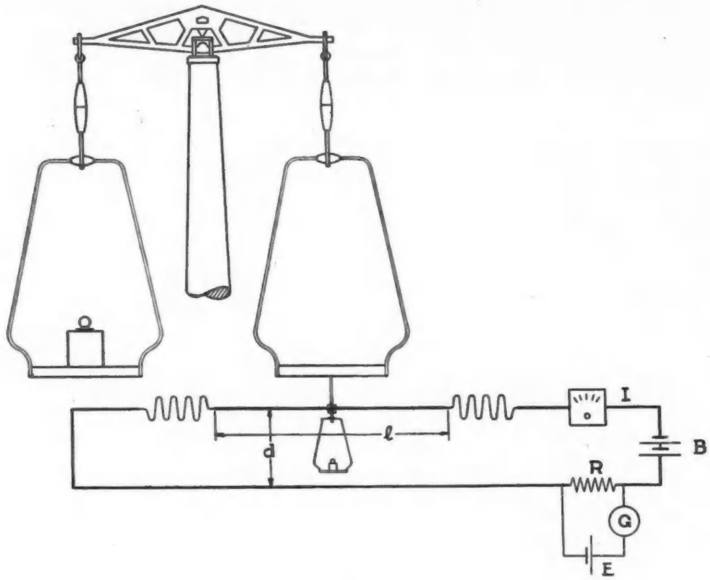

FIG. 2. The principle of a current balance as used to measure the absolute value of a current.

definition to the one already given is that the current in a conductor is unity in the cgs electromagnetic system if the force per unit length on the conductor, when placed with its length at right angles to the direction of a magnetic field having a magnetic induction of 1 gauss, has a value of 1 dyne. The direction of the force is perpendicular both to the conductor and to the direction of the magnetic induction at the conductor. This can be stated more generally by means of a vector equation in which all vectors are indicated by bold face type; the equation is

$$\mathbf{F}=I[\mathbf{l}\times\mathbf{B}], \qquad (2)$$

where **F** is the force on the conductor in dynes, **l** is a vector having a magnitude equal to the length of the conductor in centimeters and a direction corresponding to the direction of the current, **B** is the magnetic induction in gausses, I is the current in cgs electromagnetic units in the conductor of length l, and $[\mathbf{l}\times\mathbf{B}]$ is the vector product of **l** and **B**. Eq. (2) states that the force **F** has a direction perpendicular to the plane which contains **l** and **B**, and that its magnitude is given by the equation

$$F=IBl\sin\alpha, \qquad (3)$$

where F, B, and l represent the magnitudes of the corresponding vectors, and α is the angle between **B** and **l**. This more general formula can readily be applied to the case of parallel conductors which are shown diagrammatically in Fig. 1(b). If these parallel conductors represent a single circuit, then there is a force of repulsion between them, this force being represented by Eq. (2), where **B** is now the magnetic induction produced at one wire by the current in the opposite wire. Fig. 2 shows the principle involved in measuring this repulsion. The wire under consideration, of length l, is attached to the pan of a balance and is connected to the remainder of the circuit by flexible leads. When there is no current in the circuit, the balance is adjusted by placing a weight on the left-hand pan to counterbalance the weight of the wire and auxiliary pan. When current is in the circuit, there is a repulsion between the wires so that the right-hand pan of the balance moves upward. Equilibrium is restored by placing a small weight on the auxiliary pan attached to the right-hand pan.

Before using Eq. (2) to compute the value of the current, it is necessary to express the magnetic induction **B** in terms of other quantities which can be more readily measured. When the conductors are surrounded by an isotropic medium of permeability μ, $\mathbf{B}=\mu\mathbf{H}$, so that, since,

for parallel conductors, $\sin \alpha = 1$, Eq. (3) becomes

$$F = \mu H I l. \tag{4}$$

The magnitude of H at the upper wire, as the result of the current in the lower wire, is $2I/d$, where d is the distance between the wires. Inserting this value in Eq. (4),

$$F = \mu I^2(2l/d). \tag{5}$$

Since the electromagnetic force is counterbalanced by a weight of mass M, at a point where the acceleration due to gravity has a value g,

$$Mg = \mu I^2(2l/d). \tag{6}$$

If $K = \sqrt{(d/2l)}$, the equation for the current is

$$I = K\sqrt{(Mg/\mu)}. \tag{7}$$

On the right-hand side of the equation, the only quantity which is not a mechanical quantity, or a ratio of mechanical quantities, is the permeability μ of the medium which surrounds the apparatus. In the cgs electromagnetic system, the value of the permeability of a vacuum is taken as unity and the permeability of air differs from this by only a few parts in ten million. The value of a current in cgs electromagnetic units can be changed to the value in amperes by multiplying by 10.

The method here outlined can be used as a means of calibrating an ammeter which is placed in the circuit as shown in Fig. 2. However, an ammeter does not afford a precise method of measuring current. In precise measurements, it is customary to adjust the current so that the fall of potential over a standard resistance R is just equal to the electromotive force E of a standard cell. With this arrangement, a current I can be very precisely reproduced.

In an actual current balance, the straight conductors of Fig. 2 are replaced by coils of wire in order to give a larger electromagnetic force. In such a balance, the current is computed by an equation similar to Eq. (7), the difference being in the determination of the factor K. When coils are employed, K is computed from the average radii, the dimensions of their cross section, the number of turns of wire on each, and the average distance between their planes. However, every term in the expression for K is a ratio of like quantities, so that K is dimensionless.

Potential Difference

The second electrical unit which is defined in terms of mechanical units is potential difference. The definition as given in all texts is that the potential difference between any two points is the work required to transfer unit quantity of electricity between the points. If there is a current between the two points, this definition is equivalent to stating that the potential difference between them is equal to the electric power that is transformed in the circuit from, or into, some other type of power, divided by the value of the current, Eq. (8) shows the equivalence of these definitions:

$$E = W/Q = (W/T)/(Q/T) = P/I, \tag{8}$$

where E is the potential difference between the points, W is the work required to transfer a quantity of electricity, T is the time used for the transfer, P is the electrical power transformed, and I is the current. Fig. 3 shows the principle for measuring potential difference. The electrical power is produced in a generator, the armature of which is rotated at a constant speed by some device not shown. The magnet of the generator is free to rotate about the same shaft as the armature, but is constrained by the torque produced by the weight on the pan. The mechanical power is the product of the torque τ and the angular velocity ω of the rotating member. Equating the mechanical power to the electrical power, one obtains the equation,

$$EI = \tau\omega. \tag{9}$$

The potential difference can, therefore, be deter-

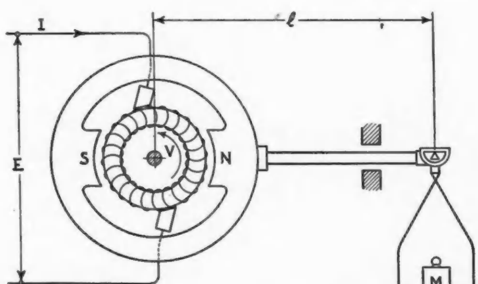

Fig. 3. A generator method by which the absolute value of a potential difference might be obtained from measurements of current and power.

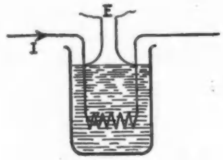

FIG. 4. A method of comparing electrical and thermal energies.

mined directly from this equation. However, this is not a practical method of making an absolute determination of potential difference, since the mechanical energy supplied to the generator is not completely transformed into electrical energy, an appreciable portion becoming heat. While the method is useful in illustrating the principles involved in an absolute measurement of potential difference, in practice some method is required in which the transformation to, or from, electrical energy is complete.

Electrical energy can be completely converted into heat. Hence, if we can measure the amount of heat per unit time developed between two points of a circuit, we can determine the potential difference, provided we know the current in the conductor. This is illustrated in Fig. 4, in which a resistance is placed within a calorimeter and the amount of heat developed is measured by the calorimeter. The equation for this method is

$$EI = JH = JM(t_1 - t_2), \tag{10}$$

where J is the mechanical equivalent of heat, H is the total heat developed per second, M is the water equivalent of the calorimeter and contents, and $t_1 - t_2$ is the temperature change per second. This method has been employed, but has two serious disadvantages. It requires a knowledge of the mechanical equivalent of heat as determined directly by mechanical measurements, which has never been done with any high degree of accuracy, and it requires that the current be known in absolute measure. Hence, this cannot be considered as a precise method.

A type of energy that can be completely converted into electrical energy is the energy of the magnetic field surrounding a current. When the current in a circuit which contains no magnetic material is stopped, the energy of the surrounding magnetic field is completely converted into electrical energy, thus inducing an electromotive force in every circuit in the magnetic field. If there is a second circuit having a definite position relative to the first, the portion of the magnetic energy of the first circuit available for inducing an electromotive force in the second one can be determined from the mutual inductance between the two circuits. This induced electromotive force can be compared, by various experimental devices, with the potential drop in a resistance which carries a current, and this comparison can be shown to be equivalent to a comparison of electric and magnetic energies. However, the introduction of a second circuit is unnecessary, for with no closed secondary circuits in the magnetic field of a circuit, all the energy of the magnetic field is available for inducing an electromotive force of self-induction. The comparison of magnetic energy with electric energy as converted into heat in a resistance will be illustrated by considering a self-inductance. For this purpose, the method of computing the magnetic energy from the dimensions of a circuit will be indicated and a method of comparing electric and magnetic energy will be outlined.

The energy W in the magnetic field of an electric circuit is given by the equation

$$W = \tfrac{1}{2}LI^2, \tag{11}$$

where L is the self-inductance of the circuit, and I is the current. However, it is shown in all textbooks on the mathematical theory of electricity, that the energy of the magnetic field is also given by the equation

$$W = (1/8\pi)\iiint_{\infty} (\mathbf{B}\cdot\mathbf{H})dV, \tag{12}$$

where $\mathbf{B}$ is the magnetic induction, and $\mathbf{H}$ is the magnetic intensity over an elementary region of volume dV. If the circuit is completely surrounded by an isotropic medium of permeability μ, then $\mathbf{B} = \mu\mathbf{H}$, so that, from Eqs. (11) and (12), the inductance is given by the equation

$$L = (\mu/4\pi I^2)\iiint_{\infty} H^2 dV. \tag{13}$$

Before L can be computed, an expression must be developed which gives H at every point in the region surrounding the circuit. It can be obtained by integrating

the equation which expresses Ampère's law for the magnetic effect of an elementary length of a circuit. This law, when expressed in vector notation, is

$$-d\mathbf{H}=I[\mathbf{r}\times d\mathbf{s}]/r^3, \tag{14}$$

where $d\mathbf{s}$ is an infinitesimal element of the circuit having the same direction as the current, $\mathbf{r}$ is the line of length r drawn from $d\mathbf{s}$ to the point at which H is to be determined, and $d\mathbf{H}$ is the infinitesimal magnetic intensity resulting from the current I in the element of circuit $d\mathbf{s}$ at a designated point. This element $d\mathbf{H}$ is perpendicular to the plane which includes $d\mathbf{s}$ and $\mathbf{r}$. The value of $\mathbf{H}$ at the point is obtained by expressing all the vectors in terms of their components in some coordinate system (often the cylindrical system), then integrating, for each component, over the complete circuit to obtain the three components of $\mathbf{H}$, and finally combining the three components to obtain the magnitude of $\mathbf{H}$. The integrals for a circuit of infinitesimal cross section can readily be indicated by making use of rectangular coordinates. Let the center of $d\mathbf{s}$ be at x_1, y_1, z_1, let $d\mathbf{s}$ have components dx_1, dy_1, dz_1, and let the coordinates of the point at which H is to be determined be x, y, z. Then, from Eq. (14), since the components of $\mathbf{r}$ are (x_1-x), (y_1-y), (z_1-z),

$$\begin{aligned}H^2_{(x,\,y,\,z)}=I^2&\left\{\int_c\frac{(y_1-y)dz_1-(z_1-z)dy_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2\\&+I^2\left\{\int_c\frac{(z_1-z)dx_1-(x_1-x)dz_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2\\&+I^2\left\{\int_c\frac{(x_1-x)dy_1-(y_1-y)dx_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2,\end{aligned} \tag{15}$$

where $H_{(x,\,y,\,z)}$ represents the magnitude of $\mathbf{H}$ at the point x, y, z. The limits of the integrals are determined by the shape of the circuit, since the integration must be around the complete circuit.

When the foregoing value of H^2 is inserted in Eq. (13), the latter becomes

$$\begin{aligned}L=\frac{\mu}{4\pi}\int\int_\infty\int dxdydz&\left[\left\{\int_c\frac{(y_1-y)dz_1-(z_1-z)dy_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2\right.\\&+\left\{\int_c\frac{(z_1-z)dx_1-(x_1-x)dz_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2\\&\left.+\left\{\int_c\frac{(x_1-x)dy_1-(y_1-y)dx_1}{[(x_1-x)^2+(y_1-y)^2+(z_1-z)^2]^{\frac{3}{2}}}\right\}^2\right].\end{aligned} \tag{16}$$

This equation shows that the determination of the self-inductance of a circuit of given shape, when immersed in an isotropic medium of permeability μ, is merely a problem of integration.

The foregoing example for a circuit of infinitesimal cross section is merely illustrative of the general procedure. In any actual circuit, the integration must extend over the cross section of the conductor as well as along its length, thus requiring the use of current density instead of total current. The present treatment has been given to show that the mathematical difficulties connected with the development of an algebraic equation for the inductance of a circuit of a given form are very great. For only a few circuits have such equations been obtained.

FIG. 5. A resistance in series with an inductance.

RESISTANCE

In order to measure a resistance by using the energy relation given in Eq. (11), the magnetic energy must be compared with the electric energy which is converted into heat in a resistance by a known current maintained for a known time. To illustrate, consider a self-inductance connected in series with a resistance, as shown in Fig. 5. Then $\frac{1}{2}LI^2$ is the energy in the magnetic field surrounding the inductor, and RTI^2 is the energy converted into heat in the resistance in time T. If an experimental method can be developed by which these energies are made equal, then, since the current in the inductance is the same as in the resistance,

$$RT=\tfrac{1}{2}L \quad\text{or}\quad R=L/2T. \tag{17}$$

This gives the value of a resistance in terms of inductance and time. From Ohm's law, the potential difference at the terminal of the resistance is known, provided the absolute value of the current has been obtained.

It is shown above that the experimental procedure in any inductance method for the absolute measurement of resistance requires that the electric energy converted into heat in a resistance be compared with the energy of a magnetic field. This requirement introduces an experimental difficulty, since the energy of a magnetic field is generally determined from the effect produced on a circuit when the current changes, whereas the transformation of energy into heat in a resistance must be measured when the current has a definite value. This difficulty may be overcome by using a sinusoidal alternating current, in which case the energy in the magnetic field of the inductance, when the current has its maximum value, is compared with the electric energy that is transformed into heat in the resistance, when the current changes from zero to its maximum value. This comparison can be accomplished by so arranging the experimental apparatus that the average potential difference at the terminals of the inductance is the same as that at those of the resistance. A

simple method of making the comparison is illustrated in Fig. 6. An alternating current is sent through the resistance and inductance, which are connected in series. With an electrometer which has a long period, the average potential difference between the terminals of the inductance is first measured, then the average potential difference across the resistance. The resistance is adjusted until these two potential differences are the same. This method has been used for the absolute measurement of resistance but is not precise; it is given solely for the purpose of illustration. The precise methods are too complicated to be included in this discussion.

To develop the equation for the absolute value of the resistance, when the average electromotive forces are equal, it is not only necessary to obtain the average electromotive forces by integration of the instantaneous values, but also to determine, by integration, the electric energy converted into heat in the resistance. Since the alternating current is sinusoidal, these integrations are readily accomplished. The inductor has an inductance L and no resistance, while the resistor has a resistance R and no inductance. The equation for the alternating current may be written:

$$i=I\cos(2\pi t/T_0), \qquad (18)$$

where I is the maximum value of the current, and T_0 is the period of the alternating current. Then, if W is the maximum magnetic energy of the inductor, and E_a the average potential difference at its terminals during a quarter cycle, beginning when the current is zero,

$$W=\tfrac{1}{2}LI^2, \quad (19) \qquad E_a=4LI/T_0. \quad (20)$$

If the average electric energy converted into heat in the resistance during this same quarter period is W' and the average potential difference at its terminals is E_a',

$$W'=RI^2T_0/8, \quad (21) \qquad E_a'=2RI/\pi. \quad (22)$$

From these four equations,

$$W/W'=4L/RT_0=2E_a/\pi E_a'. \qquad (23)$$

But the experimental procedure made $E_a/E_a'=1$. Hence,

$$4L/RT_0=2/\pi, \quad \text{or} \quad R=2\pi L/T_0. \qquad (24)$$

Eq. (23) shows that the ratio of average electromotive forces has a definite relationship to the ratio of energies.

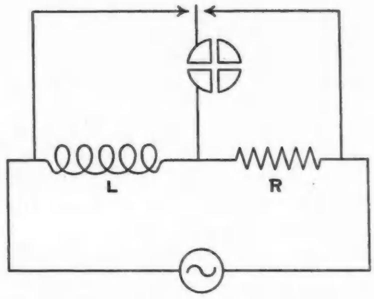

FIG. 6. Method of measuring average potential differences by means of a quadrant electrometer.

Methods have been outlined for the precise measurement of current and resistance in terms of mechanical units. A potential difference can be determined from these by electrical measurements. Thus the three electrical units which are related by Ohm's law can be established in terms of the mechanical units and an arbitrarily assigned value for the permeability of a vacuum. Also, a method for obtaining a unit of inductance has been described.

Capacitance and Quantity of Electricity

Quantity of electricity is measured as the integral of the current. Hence the unit of quantity involves the units of current and of time. In a simple case, a known current is maintained constant for a measured interval of time, so that the quantity is the product of the current and the time. In other cases, some instrument is required that will integrate the current.

The capacitance between two conductors is generally defined as the quantity of electricity on either one of them when the potential difference between them is unity. This definition requires that the electricity shall be stationary on the conductors. Hence, to obtain a standard of capacitance in the electromagnetic system, it is necessary to devise some experimental method of comparing this stationary quantity of electricity with the quantity which is defined in terms of a current. A simple method by which the quantity of electricity on a condenser can be compared with a current is illustrated in Fig. 7. The

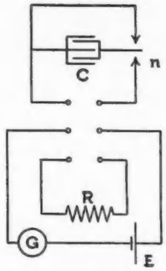

FIG. 7. Method of measuring a capacitance in terms of resistance and time.

galvanometer, G, is connected in series with a battery having an electromotive force E. A switch is arranged so that the circuit is either completed through the resistance R or connected to a capacitor of capacitance C, equipped with an apparatus that will charge and discharge the capacitor n times per second. When the battery is connected to the resistance,

$$E=IR, \tag{25}$$

where R is the resistance of the entire circuit, including the galvanometer. When the battery is connected to the capacitor and the apparatus has made contact for a sufficiently long time to completely charge the capacitor, the quantity of electricity which has gone through the galvanometer as the result of a single contact is represented by the equation

$$Q=EC. \tag{26}$$

The current of the discharge circuit, however, does not pass through the galvanometer, so that in one second, the total quantity through the galvanometer is nQ. If this gives the same deflection of the galvanometer as given by the current I, and if the galvanometer can properly integrate the current through it, then, since $I=nQ$, the combination of Eqs. (25) and (26) shows that

$$C=1/nR. \tag{27}$$

MAINTENANCE OF STANDARDS

The foregoing principles are applicable for the establishment of the electrical units. However, with the accuracy demanded at the present time, there are only a few laboratories that are equipped to carry out the experimental work involved. It is, therefore, of importance to consider the methods by which units, when once established, can be made available to other laboratories. It is not feasible to maintain standards of current or of quantity of electricity. Hence, there are only four different electrical units for which standards are regularly maintained. These are: resistance, electromotive force or potential difference, capacitance, and inductance.

The unit of resistance is maintained by standard resistors, each of which consists of a coil of wire. Most of these standards are made from manganin wire, but wires of other materials have recently been proposed. The national standardizing laboratories maintain groups of from four to ten 1-ohm resistors which are frequently intercompared, and from the mean value of which the ohm is maintained. A 1-ohm resistor can, in some of the national laboratories, be compared with a similar coil with an accuracy of a part in ten million. However, even the best coils may change by an easily measured amount during a year, so that the actual value of the ohm cannot be maintained closer than a few parts in a million.

The unit of electromotive force is maintained by means of saturated cadmium cells. Each national laboratory has a large group of these cells, often as many as 20, the average of which is assumed to remain constant. Within a few years there have been improvements in the construction of these cells so that there should be less variation between the national laboratories than has been the case in the past. In some laboratories, intercomparison of cells is now being made with an accuracy of a few parts in ten million. As the temperature coefficient of these cells is about 40 parts in a million per degree centigrade, very accurate temperature control is required for making such measurements.

The unit of capacitance is maintained by mica and air capacitors. Mica capacitors are more stable than air capacitors, but even these are not as stable as standard resistors and standard cells. At the National Bureau of Standards, the values of the standard mica capacitors are determined once or twice a year in terms of resistance and time. A variation of a part in ten thousand often occurs between measurements, even in the best

mica standards now available. Air capacitors are standardized whenever a value is required to a greater accuracy than a part in a thousand.

A standard of inductance usually consists of a coil of insulated copper wire wound on an insulating spool. Very few studies have been made to show how well such a standard will maintain its value. However, it is known that many of them change their value by several parts in ten thousand in a relatively short time. Many laboratories do not depend on these standards but make all measurements of inductance directly in terms of resistance and capacitance.

This paper has merely outlined the principles underlying the establishment of the electrical units in the cgs electromagnetic system and has briefly indicated the method by which they are now maintained in the national laboratories. It is shown that the whole system is derivable from Ampère's laws concerning the magnetic effect of the current and from the doctrine of the conservation of energy. The relations between the units of the electromagnetic system and the ohm, ampere, volt, etc., are not given, since they can be found in many textbooks. The question of reproducible units has been entirely avoided, since it merely introduces an unnecessary step in the development of the practical units. Moreover, the decision has been definitely reached, by the International Committee of Weights and Measures, that the practical units will be directly based on the electromagnetic units beginning January 1, 1940.

Training of Physicists for Industrial Positions

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To those of us who have been engaged in industrial research for a decade or more, there appears to have been a social upheaval in the realm of the physical sciences in which the researcher in practical or applied fields has been lifted from the gutter of so-called "prostituted" science and at least his better qualities held up as ideals for aspiring young physicists to emulate. Seriously, it is very significant that a symposium should have been arranged by the American Association of Physics Teachers[1] to consider such an important problem as the "Training of Physicists for Industrial Positions." For, just as an idea was conceived in the mind of Mark Twain that the religion of a sun worshipper, sitting in a public place and alternately going through the motions of heavenly appeal and prostrate humility, might become a religion worth having if a crank were attached to his head and made to turn the wheels of a productive machine, so has the idea been growing that the discoveries of pure science are important in almost direct proportion to their practical value, that is, to the influence they exert on the lives of people.

It is my purpose to discuss this question from the viewpoint of an employer of technical men, and not to propose a plan for the teaching or training of students. The latter is a problem for physics teachers.[2] My position is more nearly akin to that of the small boy in a poetry contest who, after hearing one youngster recite:

> My name is Dan,
> When I'm a man
> I want to go to Japan
> If I can,
> And I think I can;

and another continue with:

> My name is Sadie,
> When I'm a lady
> I want to have a baby
> If I can,
> And I think I can;

raised his voice and fairly shouted:

> My name is Sam,
> When I'm a man
> I don't want to go to Japan.
> I want to help Sadie with her plan
> If I can,
> And I think I can.[3]

[1] Joint meeting of the Founder Societies of the American Institute of Physics, New York, Oct. 29–31, 1936. The present paper was presented in this symposium.

[2] See H. L. Dodge, "Training of Physicists for Industry—From the Point of View of the Educator," Am. Phys. Teacher **4**, 167 (1936).

[3] Related by K. T. Compton before the U. S. Institute of Textile Research; see Textile Research **5** (Dec., 1934).

My purpose in accepting a place in the symposium is to help the Association of Physics Teachers with its plan, if I can—and, I might add, I think I can.

Recently I had called to my attention a published symposium[4] on the training of executives for modern day business, with some of the country's best known industrial leaders as authors. The subject matter is presented under such titles as "General Executive Types in Past Periods," "What Personal Qualities Make a Modern Executive," "What the New Type Executive is Like," etc. After learning from this text that the year 1936 marks the beginning of a new period in executive management which is characterized by "professional, technical executive management of the higher, broader type" and by "extensive technological modernization," we read that the modern executive must have "technical knowledge, experience and training" and "power of analysis;" and a "strong scientific spirit and outlook, using the scientific approach to problems of markets and management as well as to manufacture." We are further informed that:

"The modern executive of large scale business touches many sciences—chemistry, electricity, metallurgy, etc., psychology, engineering, mathematics, sociology, economics, statistics, finance, accounting, advertising, credit, agriculture, transportation—and in addition, pure science. He is also more certain to be able to distinguish between fact and opinion; between prejudice, habit, or personal mood and temper, and the exact realities of a situation; and he is less likely to be easily satisfied with his own opinions and more likely to dig for full information before asserting an opinion."

According to Chap. III, there has been a "decline of experience as a major executive virtue." We are told that:

"The entire top-executive basis of thinking, as a result, has shifted from the premise of 'experience' to the premise of 'research,' analysis and experiment. Business became what philosophers call 'pragmatic,' and 'objective.' That is to say, it subscribed more and more to the *scientific* temper and outlook, instead of the *traditional* temper and outlook; adopted the point of view that 'that is right which works.' In consequence modern executives say, in effect, 'let us stop being subjective and traditional—let us discount our own ideas, our experience, our beliefs and set notions, and start out to *find out*, in the impersonal, detached, attitude of science. What do we care whether we arrive at our desired result (progress, profit and effectiveness) through trying something startlingly new, or through listening to the so-called voice of long experience? We'll take nobody's say-so; not even that of the man who has been in the business all his life. We'll make tests and experiments, use surveys, researches and specialized counsel, and work our way toward our goal cooly and without the slightest pre-conceived prejudice, and cheerfully reverse our own ideas, everybody's ideas, if necessary.'

"Thus died the shibboleth of 'long experience.'"

The important role which research is destined to play in industry is outlined in a chapter by Henry P. Kendall, ex-president of the Taylor Society, past chairman of the Government Business Advisory Board, and an engineer, textile manufacturer and industrial leader of no little standing. He writes:

"The very breath of our modern day is impregnated with the research spirit. Farmers are feeding their live stock on a measured calory basis, decided by experts; not on their personal hunches, traditions, or enthusiasms. New York clothing makers are counting with hand-counting machines the number of women on Fifth Avenue, Bar Harbor or Palm Beach who wear blue or black or what length skirt—instead of getting up style hunches or enthusiasms of their own. There is no detail too small to be measured nowadays; instruments exist capable of measuring the heat of a match lit twelve miles away. The whole world of life is a research adventure, and the smallest task in modern business and industry is full of factors of genuine research importance."

In another place Mr. Kendall states:

"We are just beginning to grasp the significance of the research idea in industry. Our own organization is learning that young men from the schools and colleges are happier and contribute more to the business when they are encouraged to work in the research spirit and are dominated by the research idea rather than by the old, routine idea which deadened initiative, ambition, and the finer capacities. An organization, steeped in the research idea, its executives and workers all thinking of problems and studying carefully their solutions with something of the zest the scientist brings to his work, is something more than an organization. It is an organism with opportunities for growth stretching out both for the individual and for the company."

I have chosen to preface my remarks by citing this recent symposium on the training of executives for industry because of its similarity in purpose to the present symposium. If I gather correctly its message, physics teachers will be called upon in the future to train business executives as well as research workers.

Many of the qualifications listed[4] in the description of the modern executive are also quali-

[4] *For Top Executives Only* (Business Bourse, New York, 1936).

fications that should be cultivated in the personality of the research worker. Take this one, for instance:

> "Boldness of imagination, daring in conception, courage for change, vigor of conviction."

Distinguished success in any walk of life is dependent upon imagination as an intrinsic trait of character. So important is this trait in research work that I feel inclined to place it at the top of the list of fundamental requirements. It should be cultivated at all times. Perhaps the best way to do this is to give the student greater breadth of training. He should be offered a variety of courses in science and perhaps a liberal number in other fields, such as history, government, economics, literature, and philosophy, including ethics and logic.

The immortal Faraday sensed the importance of imagination in research and wrote in his diary: "Let the imagination go, guiding it by judgment and principle but holding it in and directing it by experiment." Evidently he also sensed another very important capacity which should not be forgotten in the development of the imagination—ability to *control* the imagination processes. Someone has said, "Imagination without control in its most extreme biological sense results in dementia praecox." Development of sound judgment and an analytic sense must not be sacrificed at the expense of cultivating the imagination.

Curiosity is an attribute that should be encouraged along with the proper functioning of a vivid imagination. Fortunate, indeed, is that individual who has an innate curiosity in his surroundings, whether things or people.

Let us look at another qualification of the modern executive:

> "Strong scientific spirit and outlook, using the scientific approach to problems of markets and management as well as to manufacture. A humble objective attitude even in regard to himself; free use of counsel and research to check judgment."

Thinking is the hardest thing in the world; yet it brings us the greatest ease. A child begins to think by making judgments, comparing one thing with another, noting similarities and differences. His education should develop faculties for correcting these judgments promptly. The efficiency of his thinking depends upon the mastery and use of the accumulated thoughts in any field of encounter. A student should, therefore, be given a broad training and should be aided in acquiring the study habit.

Research is essentially that process of thought which analyzes a problem, breaks it down into its parts for solution and then interprets the results in keeping with the total problem. In the training of young physicists for industrial positions, they should, therefore, be given greater opportunity to solve simple problems which arise naturally out of their environment. Too often they are allowed to pass a course because of ability to follow instructions and memorize. They should first of all be taught to think and not simply to sponge up information to squeeze back at examination time. A walking encyclopedia may be a total failure in applied science.

Here is a characteristic of efficient executives which is of utmost importance to industrial physicists:

> "Powers of expression, publicity, teaching; ability to cooperate, magnetism for leadership."

As H. G. Wells commented in his *New Worlds for Old*,

> "The main difference of modern scientific research from that of the middle ages lies in its collective character, in the fact that every fruitful experiment is published, every new discovery of relationship explained. . . . Scientific research is a triumph over natural instinct, over that mean instinct which makes a man keep knowledge to himself and use it slyly to his own advantage. . . . To science this is a crime."

The research worker in industry must be a social individual. He must have the ability to cooperate unselfishly, to express himself freely and intelligently in both technical and nontechnical language, to teach tactfully and counsel wisely those engaged in production. There is no place for a self-centered, eccentric investigator in industrial research.

The inclusion of a technical training and teaching ability among the qualifications of an executive is probably the result of the inability of the scientist in industrial research to convey his ideas and interpret his results so that executives can fully comprehend them. Distrust of research on the part of many laymen in industry

is the direct result of a language barrier between them and the technically trained men.

Too few graduates of technical schools are able to express themselves intelligently in oral or written reports. What they learn in their English courses is either inadequate or soon forgotten. Some of the reasons for this are: (1) physics students are taught to use the shorthand of mathematical symbols in expressing relationships; (2) they are forced to slight English and English composition in order to obtain the prescribed technical subjects in the allotted time; (3) not enough premium is placed on accurate expression in technical courses.

Physics teachers can (help the student) develop, or at least preserve, ability in English expression, but generally neglect to do so because of the effort required. For example, no better training in expression is possible than that obtained through careful note-taking. This does not mean that notes should be taken in the form of dictation as this is extremely wasteful, and sometimes dangerous. Moreover, the student should not be required to take voluminous notes. Too much attention is diverted from the remarks of the teacher. The student should take down the outstanding points and then, as soon as possible after the recitation, write them in the proper form in his notebook. Such exercise furnishes excellent training in English expression, demands the attention of the student during the class period, requires discrimination in the selection and arrangement of the material, and impresses the facts recorded in such a way that they are not easily forgotten. Of course, to be of most value the notes should be inspected and corrected, the chief objection being that it takes so much of the teachers' time.

Another opportunity for training in English expression offers itself in the writing of laboratory reports and answers to examination questions. But here again the opportunity is too often disregarded. There is an increasing amount of propaganda and a growing tendency for physics teachers to adopt standard printed forms on which reports of laboratory experiments may be returned by the mere writing of a few words in blank spaces. Similarly, novel examination sheets are now employed to render grading objective. The grading of such printed forms is simple, but the benfits in the development of self-expression are practically negligible. It is small wonder then that when an occasional examination requiring written answers is given, physics teachers obtain such a statement as this one for Pascal's law: "Pressure exerted on a liquid is diminished to all parts of the container proportionately;" or, this one for the complete conditions for equilibrium: "The algebraic sum of a body acting in one direction must equal the algebraic sum acting in the opposite direction."[5]

I cannot refrain from considering one more qualification of an industrial executive which has equal significance as related to the applied physicist:

> "Emotional maturity, balance; effective coordinated drives, and mastery of emotional nature; sympathy, humanity, insight; power of decision, will and sustained effort."

Education for a research worker, as well as for all others, should help him to stand off from his environment and look at it in a cool, analytical manner. It should teach him orderly processes of thought and a control of muscles. Even more important, it should give him a general philosophic attitude, poise and determination to win or lose gracefully, pleasantly, no matter how much time or patience is required. Accordingly, his training should prevent him from being an eccentric in his special field, should make him a livable human being who can talk about more than one subject. It should teach him how to control people, whereby he may succeed in getting his own way in his special field. The ability to influence others by one's determination, poise, and knowledge is even more important in industry than in a university, where only the poised and orderly people who have breadth of character, a broad outlook towards life, and the ability to influence other people because of their tolerance and understanding can, or should, become professors.

Another important trait to be encouraged is aggressiveness. Aggressiveness arises out of good health, a good physique, good living conditions, and, frequently, family responsibilities. The development of a research worker, therefore,

[5] These and many other distorted replies to examination questions were reported at the 1936 meeting of the Southeastern section of the American Physical Society by George V. Page.

should involve participation in athletic games and outdoor sports and should not permit him to become an introvert. Scientific schools tend to give inadequate attention to this very important training for later success.

Doubtless many will feel that the personal qualities have been over-emphasized, but if this has been done, it is because of a firm conviction that the *man* is more important than the *courses*. I am certain that those who have had experience in industrial research, particularly in smaller laboratories, will agree that it is generally more difficult to translate results into practise and follow them up in production than to obtain data and draw conclusions therefrom. And the success which one attains in turning laboratory results into practical usage is generally closely associated with his personal qualifications, including his capacity for self expression.

Let us now turn to the difficult question of what technical subjects should be included in an education for industrial research. There are so many different types of research being conducted in the various organizations and so many different subjects under investigation that we can only hope to consider the broad fundamentals and draw general conclusions.

As has already been mentioned,[2] a questionnaire was sent from the office of the American Institute of Physics to about fifty research workers who have generally been successful in industrial work. Those receiving it were asked what courses, graduate and undergraduate, were of greatest value, and what elements were considered important but lacking in their education. The answers were surprisingly varied. It would be practically impossible to arrange a curriculum to include all of the courses or subjects mentioned.

Perhaps the questionnaire was not the best method of obtaining the information. Dr. Frandsen, a noted psychologist, once said,

> "You can't learn anything about people by the questionnaire method, because they don't know themselves. Prejudice always influences questionnaires. If you want to know why children run away from school, don't ask them now, or don't ask them when they grow up. Study them and find out for yourself."

Flattery is suggestive. If a person is asked to check the things that made him a great man, he generally obliges and seeks to cooperate by checking the things the inquisitor wants him to check. Perhaps some such suggestion was carried in the questionnaire sent out by the Institute of Physics. For, after stating that the list of persons to whom it was sent were selected from a group of successful or useful industrial physicists elected by the Advisory Council on Applied Physics, the letter of transmittal went on to say: "It is a well deserved tribute and may be a source of personal satisfaction to you that a number of the replies mentioned your name." In some cases it seems that this personal tribute might have prompted the person replying to list the names of the most difficult courses he had taken in his graduate study or the most helpful specialized courses in his particular field of study. Many others, however, apparently grasped the significance of the questionnaire and looked beyond their immediate field of specialization to the broader aspects of the training of research workers for industry.

An attempt to analyze the answers, however, and to draw some general conclusions was difficult, for there were many contradictions. For instance, there were such replies as these: "More physics laboratory *without* supervision," and "More physics laboratory *with* supervision." One person laid emphasis on subjects that provided tools for acquiring data. Another said the principles of a subject are far more important than tools or methods.

Many listed English composition and English as the subjects which were most lacking in their education, and the ones which were of most value. Yet it is noteworthy that all of these men achieved positions of prominence in research organizations even with this deficiency in English. Not a few sensed the importance of non-technical, character-forming, personality-building education, and in some cases their replies took the form of voluminous discussions on the importance of cultivating certain listed traits.

The part to be played by the teachers was mentioned, but perhaps not sufficiently emphasized. Ability to inspire, particularly in the earlier courses of college physics, was stressed. Quite a number voiced the opinion that every faculty should include at least one teacher who has had experience in industrial research. Let me add,

pleasant and *successful* experience. These suggestions are especially valuable and should provoke considerable thought on the part of the department heads and college executives.

Among the subjects mentioned as of most value were the following, listed according to decreasing frequency of citation:

Physics	Physical chemistry
Mathematics	History
Chemistry	Economics
Languages	Biology
English and English composition	Philosophy
Engineering	Laboratory and shop work
Mechanical and classical physics	Mechanical drawing

Numerous other studies and special courses were listed, but never by more than one individual.

In answer to the inquiry regarding courses which were important but lacking in their training, the group contributed the following replies, also listed according to decreasing frequency of citation:

English and English composition	Chemistry
Mechanics and classical physics	Mathematics
Physical chemistry	Engineering
Languages	Public speaking

Here again those subjects listed but once are omitted. The fact that this list is shorter than the previous one is noticeable. It will be observed that I have grouped mechanics and classical physics together and have not included them under the general heading of physics. The listing above is not absolutely accurate, therefore, for perhaps many who used the general term physics had reference to the classical phase of the subject. The newer, theoretical physics has little general application in industry as yet, but mechanics and classical physics form the background for research in any branch of applied science.

The need of an understanding of the languages, mainly German and French, was stressed. It seems inefficient to take up valuable time in college with formal teaching of the languages, when this can be more effectively done in the secondary schools.

The stress placed on mathematics and chemistry seems to be justly deserved. In the smaller laboratories, particularly, a practical knowledge of these subjects is of vital importance.

The placing of English and English composition at the top of the list of those courses which were lacking in the training of the physicists interrogated is natural in view of what has been previously said. However, it is surprising to note that shop work and mechanical drawing are so low in the list of the most valuable subjects. Both experience and observation teach that a mechanical sense, that is, ability to use one's hands in manipulative and creative work, and ability to design and construct equipment not available from instrument manufacturers, is very fundamental in practical research. Perhaps the failure to sense the importance of these subjects lies in the fact that so many of those questioned were employed in large organizations having design engineers, draftsmen and model shops. Certainly, shop work and mechanical drawing rate more consideration in any training program for industrial physicists.

Another still more surprising revelation was the fact that statistics was mentioned in only one reply to the questionnaire. It may be that the general heading of mathematics is flexible enough to include statistics, or that economics is sufficiently broad to include some phases of statistics. I should like, however, to emphasize the importance of a fundamental training in statistics and theory of probability. As W. A. Shewhart[6] of Bell Telephone Laboratories has said,

"Even though engineers have heard much about statistical methods and their application to education, sociology, economics, etc., they have been inclined to stand aloof and say, 'Well, these methods may be all right for the fellow who deals with such inexact sciences as education or economics, but thank goodness we don't have to depend on their use because we are dealing with the application of exact sciences such as physics and chemistry.'"

Yet,

"We hear distinct rumblings of a revolution in the camp of the exact sciences. The concept of exact is overthrown for the moment at least, and in its place statistical concept holds sway."

As Shewhart[7] says elsewhere,

"No longer do we think of physical properties as constant quantities. Instead they are *frequency distribution functions*. In the same way, we think of relationships between the physical quantities as frequency distributions in two or more dimensions. For these reasons it appears that prediction must be based upon samples and that *prediction within limits* is the only kind possible. The need for sampling theory appears to be universal."

[6] J. Am. Statistical Assoc. **26**, 215 (1931).
[7] Am. Math. Mo. **38**, 245 (1931).

Let us cite one example of the many needs for familiarity with sampling theory and statistics. Suppose that it is essential to know the tensile strength of some product of manufacture or of some machine part. We select a sample and submit it to a stress sufficient to produce a rupture. We then repeat the operation on another sample and possibly find the break occurs under a radically different stress. As a matter of fact, we are not directly concerned with the result for either sample. Our interest is in how nearly these samples represent the group of untested materials and this can only be determined by making a sufficient number of experimental determinations and interpreting the results by statistical analysis and probability theory. By all means, the training of physicists for industrial positions should include a practical course in comparative statistics.

Speaking of statistical analysis, or sampling and probability theory, it would be interesting to know how well the small group of men replying to the Institute's questionnaire represented the total group employed in industrial research in this country. This could be determined if an up-to-date classification of industrial research laboratories and their personnel were available. The most complete compilation of this type which I could find was made in 1933 by Clarence J. West and Callie Hull.[8] Of the 1575 laboratories listed, employing some 27,500 individuals in research, approximately 6 percent reported one member on their technical staff; 27 percent, 3 or less; 50 percent, less than 5 members; 75 percent, less than 10; 95 percent, less than 40; and only 2.5 percent (or 37 laboratories), more than 100. Yet these 37 large laboratories employed almost half of the total number of people engaged in industrial research. Of those replying to the Institute's questionnaire, 60 percent were employed in this group of large laboratories.

The average number of employees in each industrial laboratory in 1933 was 18. The average number employed at that time in each laboratory represented by those replying to the questionnaire was 456. This means that these replies failed to reflect the point of view of the small research organization.

Altogether, 209 laboratories, or 13 percent of the total number reported in the bulletin,[8] listed physicists on their staffs. The actual number of physicists was less than 2.5 percent of the total number of research employees. About half of the total were chemists and engineers. Roughly 60 percent of the 209 laboratories reporting physicists, or 124 laboratories, listed but one physicist. Of these 124, about 23 percent reported no chemists, 20 percent, no engineers, and 75 percent, no metallurgists.

So it is evident that a large percentage of the physicists entering industrial employ will be dependent upon their own resources. They not only will have to map their own programs and solve their own problems, but will be called upon to interpret those solutions personally for the management and for those in charge of manufacture. Contrast this situation with that in one of our largest industrial laboratories[9] today, thoroughly equipped with a technical library, model shop, patent department, bureau of publication, etc., and employing over 1300 male American day college graduates who have received their degrees from 184 different educational institutions. Of these, 6.5 percent have doctor's degrees and 14.5 percent, master's degrees. A number of others have had some graduate study.

As regards the training of these technically employed graduates in this large laboratory, in the neighborhood of 60 percent of those with doctorates specialized in physics, 15 percent in chemistry, and the remainder in engineering or other subjects. Of those receiving master's degrees, approximately 50 percent were in physics, 5 percent in chemistry, and the remainder in engineering and other subjects. Of those with baccalaureate degrees, about 90 percent took their work in engineering.

There are few large research organizations such as the one just cited. The majority of physicists in industry are working in small laboratories, and the chances are in favor of this number increasing. At least, it is safe to predict the entry of more and more companies into research, and all laboratories are small at their inception. In arranging a curriculum for training students for industrial

[8] Bull. 91, National Research Council (ed. 5, 1933).

[9] Bell Telephone Laboratories, New York City.

positions, therefore, the importance of the small laboratory should not be slighted. Any physicist adapted for employment in a small organization should readily qualify for a position in a larger concern. The reverse of this may not always be true.

Many of the small laboratories being organized at the present time are in the basic industries and are concerned with the development and production of commodities that are indispensable for our very existence, namely, food, clothing, and shelter. These are the old industries, those which have been with us in some form or other since antiquity. For some reason, the spirit of research was slow to develop in these basic industries. Rather, it found expression in industries that are contributory rather than basic, such as transportation, communication, etc. There is probably more research being conducted in such a minor field as refrigeration than in the cotton textile industry.

New developments in transportation and communication have shortened distances and practically annihilated time. The country's largest industries are working over-time to supply products which, under the most generous classification, must be rated as luxuries rather than essentials. One walks through a cotton mill and sees clumsy cast iron machines bearing dates of the last century and weaving yarn into cloth according to the same principles as were employed in the weaving of rushes into mats by primitive peoples. At the same time, one sees both employees and employers of these same mills driving automobiles of next year's design.

According to the 1933 classification of industrial laboratories,[8] there were about twice as many people employed in the laboratories of the automotive industries as in those concerned with food products. Moreover, of the 37 laboratories reporting 100 or more employees at that time, 18 were related to the automotive industry and concerned with the development of either automobiles, tires, or oils. Eight of the remainder were concerned with electrical products, including the telephone; 3 with chemicals; and 8 with special materials.

In organizing laboratories concerned with the basic products of food, shelter, and clothing, the physicist may have to overcome a certain amount of distrust on the part of the layman. There has been a great deal of time and effort wasted in improper and untimely research in these industries. Things have been generally mixed up and measurements made without any control or any clear idea as to the goal. As Vannevar Bush[10] has stated:

> "The idea has unfortunately been prevalent that one may buy a research laboratory ready made from the instrument makers, and by hiring a doctorate graduate and turning him loose, be securely embarked on a program of research that is bound to yield results which will revolutionize a part of an industry and cause it to produce desirable products with a high margin of profit. The trouble with that scheme is that there is everything present but the program and the mature and experienced brains to guide it. . . . The principle essential to an intelligent research program is not apparatus, or funds, or young research workers; it is a man; a mature research worker with a thorough knowledge of his field, an understanding of his profession, a vision of the possibilities, a courage to attack the unknown, a patience that is inexhaustible, a kindly humanity that will cause his co-workers to rally about him with enthusiasm. Find such a man and the rest of the research laboratory and program will appear."

[10] Introduction to *Textile Research—A Survey of Progress* (Technology Press, Cambridge, Mass., 1932).

Meetings of the Kentucky Chapter

THE autumn meeting of the Kentucky Chapter of the American Association of Physics Teachers, held on November 14, 1936 at Transylvania University, was devoted to *Physics in Industry*. Papers given were: "Electronics and Industry," A. D. Hummell, Eastern Kentucky State Teachers College; "Physics in Industry," J. H. Graham, Dean of the College of Engineering, University of Kentucky; "Industrial Physics at the University of Michigan," J. G. Black, Morehead State Teachers College; "The Engineer as a Physicist," D. M. Bennett, University of Louisville; "National Movements," Jarvis Todd, University of Kentucky.

At the meeting held on January 16, 1937 at the Eastern Kentucky State Teachers College, the general topic was *Developments in Physics During 1936*. Papers given were: "Rectifying Properties of Crystals," Guy Forman, Western Kentucky State Teachers College; "Cosmic Rays," R. B. Sawyer, Centre College; "Zeeman Effect Observations," R. A. Loring, University of Louisville; "Elementary Particles," L. A. Pardue, University of Kentucky.

Some Fallacies in Textbooks on Modern Physics

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By fallacies we do not mean arithmetical or mathematical blunders, but incorrect statements of physical principles or illogical, incorrect arguments used in deriving correct statement of such principles. All the illustrations below, except that from Drude's book, are taken from texts chiefly in modern physics, published within the past few years. The parts in quotation marks are the present writer's condensed statements of the arguments presented in the texts. In most of the points here presented, the authors were merely off guard; but in some cases, notably those concerning the pressure of light and the reconciliation of the Newton and Huygens point of view, the statements criticized are copied from one text to another.

Conservation of linear momentum

Perhaps the most amazing illustration of an illogical argument is the following, as set forth in a recent survey text in physics:

> "A tennis ball of mass m and velocity v is thrown against a wall. It returns with the same velocity v' as it had in striking. Since the mass is constant we have $mv = mv'$. This illustrates the law."

The authors apparently did not regard momentum as a directed quantity, nor did they call attention to the fact that the law still held (though the illustration would have been no more evident than in the case they give) had a piece of putty been thrown against a wall and stuck there. As this law is one of the most fundamental in the whole realm of physics it ought to be stated and illustrated correctly.

Velocity of escape

> "If a body is projected vertically upwards with a speed of 7 mi./sec., it will escape from the earth. If the direction of projection is not vertical, the velocity must be such that its vertical component is 7 mi./sec."

The major axis of the orbit described by a body under the inverse square law of attraction depends only on the total energy of the body. For a particle of mass m and velocity v on the surface of the earth of mass M, the total energy would be $\frac{1}{2}mv^2 - GmM/r$ where r is the distance between the centers of m and M. This, of course, is independent of the direction of v. If the total energy is zero, the orbit is a parabola and the body will escape from the earth whatever its direction of projection, provided only that this direction is above the horizontal; that is, provided that the body does not strike the earth.

It should have been pointed out in the text in question that the orbit, whether ellipse, hyperbola, or parabola, described by a body under the inverse square law of attraction, depends only on the energy. This is a matter of great importance when we are dealing with Bohr orbits or with the scattering of α-particles by gold foil. Although in the latter case we change from attraction to repulsion—in which case the orbit is necessarily a hyperbola—still the idea of total energy is essential. Given a certain energy, the direction of projection does not alter the major axis of the hyperbola, but merely the direction of the asymptotes.

Kepler's third law

This is one of the important laws holding when a body describes an elliptic orbit about a large mass under an attractive force that varies inversely as the square of the distance. It is generally stated thus: The squares of the periodic times are proportional to the cubes of the *mean* distances from the sun to the planets. But what kind of a mean is to be taken? Ordinarily we would refer the orbit to the focus as origin and major axis as zero direction. If we find the mean distance from the focus to the ellipse, with the angle between the radius vector and major axis as variable, it turns out to be the semi-minor axis b. This would be the significance which we would attach to the *mean* distance and it would make the statement of Kepler's law entirely incorrect.

If, however, the variable x be taken as along the major axis, and if the mean be so computed, it is found to be equal to the semi-major axis. This is a most unusual interpretation to be attached to the idea of the mean distance.

A satisfactory statement of Kepler's law then seems to be merely this: The square of the periodic time is proportional to the cube of the mean of the greatest and least distance from the planet to the attracting center. If we ignore the fact that Kepler found it necessary to consider the *mean* of certain observed distances, and if we state the law without using that historic word, we would merely say that the square of the periodic time is proportional to the cube of the semi-major axis of the orbit.

Concerning the closest packing of spheres

In experiments on the diffraction of x-rays by liquids, it is customary to associate the distance between corresponding diffracting electrons with the smallest distance between molecules. It appears that this distance is incorrectly computed in some texts.

The computation leads to a consideration of the closest packing of spheres. Consider spheres in a tetrahedron. Every sphere is in contact with 12 spheres—the greatest possible number. This then is the closest packing. If there are n spheres on an edge, the total number of spheres in the tetrahedron is $n(n+1)(n+2)/6$. When n is large this equals $n^3/6$. The volume is $nd \times nd\frac{3}{4} \times (nd/3)\frac{2}{3} = n^3d^3/6\sqrt{2}$, where d is the diameter of a sphere. Hence, as $n^3/6$ spheres occupy this volume, each sphere reserves for itself a volume of $d^3/\sqrt{2}$. Since N spheres occupy a volume of M/ρ, where N is the Avogadro number, M is the molecular weight and ρ is the density, then to each sphere is apportioned a volume of $M/N\rho$. Hence $d^3/\sqrt{2} = M/N\rho$, or

$$d = (M/N\rho)^{\frac{1}{3}}2^{\frac{1}{6}} = 1.12(M/N\rho)^{\frac{1}{3}} \text{ cm.}$$

If the spheres were arranged along x, y, z axes mutually at right angles, every sphere would be in contact with six, and every sphere would reserve for itself a volume of d^3 instead of $d^3/\sqrt{2}$.

The pressure of light

In Drude's *Theory of Optics* there is a subtle discussion of the difference between light falling upon and light entering a body. As a result of this discussion Drude arrives at the conclusion that in a directed beam of light there is a pressure equal to the energy density. Perhaps he felt reassured as to the correctness of his argument by the fact that Maxwell, Bartoli and Boltzmann had reached the same conclusion.

Doubtless it is a variation of the argument set forth in Drude's *Optics* that is found in various recent textbooks. In a text on modern physics which appeared a few years ago, the argument is based on the law of the conservation of energy, thus:

> "A black body of unit cross section is allowed to move against a light beam of density E with velocity v. During time t more energy enters the body than before by the amount Evt. There is thus a gain in energy during that time of amount Evt and this must come from work pvt expended in pushing the body against the beam. Hence $p=E$."

But this argument fails to consider the subsequent history of the energy which is absorbed by the body whether at rest or in motion. Neglecting this important point, and using the same kind of reasoning, we can prove that the pressure is zero. For example, picture a very long beam of light falling upon a black body B. If B is at rest an amount of energy Ec enters B each second. The long beam loses Ec and B gains Ec. No energy is lost or gained. Now let B advance against the light with velocity v. Then the light beam loses $E(c+v)$ and B gains $E(c+v)$ per second. No energy is lost or gained. No work is done in pushing B against the light. The pressure is zero.

The fault in this argument lies in the failure to follow the subsequent history of the energy absorbed by the black body. It is seen that the law of radiation of such a body must be considered. Then we are led to Boltzmann's derivation of the Stefan fourth-power law; or, assuming this law, we may derive the value of the pressure in a *volume* of random temperature radiation, namely $p=E/3$. Using this result we can show that in a *directed* beam $p=E$.

The argument based on the simple application of the first law of thermodynamics but neglecting the equally important second law has appeared in other texts since its statement in the text on modern physics to which reference has been made. Had the authors of these texts remembered that the pressure in a beam of projectiles is equal to $2E$, whereas their argument would have made it equal to E, they would have seen that their method was fallacious.

Had the beam of light been allowed to fall upon a totally reflecting surface instead of upon a black body, the argument would necessarily have been abandoned. Then one of two methods might have been followed. We might have enclosed the radiant energy and have proceeded as Boltzmann did, utilizing Stefan's law. Or we might have used the Fresnel picture of waves in an elastic medium, the energy of which, given a certain amplitude, varies inversely as the square of the wave-length. This leads, as Larmor has shown, to the result $p=E$, where E is now the *total energy* in front of the mirror. It is interesting to note that it is only for this kind of wave motion, namely one for which the energy varies inversely as λ^2, that the relation $p=E$ holds.

To reconcile the de Broglie and Bohr pictures of the hydrogen atom

We assume the de Broglie relations $E=mc^2$ and $f=E/h$; also the speed in the nth circular Bohr orbit, $v_n=2\pi e^2/nh$. The fallacy in question is as follows:

"The frequency f_n of the associated de Broglie waves is

$$f_n=\frac{mc^2}{h}=\frac{m_0c^2}{h\sqrt{1-\beta^2}}=\frac{m_0c^2}{h}\left(1+\frac{2\pi^2e^4}{n^2h^2c^2}\right).$$

Then $f_n-f_{n'}=(2\pi^2me^4/h^3)(1/n^2-1/n'^2)$. This is the Bohr relation."

It is seen that in the expression for hf_n the first term m_0c^2 is constant and the second term, $2\pi^2m_0e^4/n^2h^2$ is $\frac{1}{2}m_0v^2$, the kinetic energy. Thus, if we leave out a constant quantity, the frequency difference in the de Broglie frequencies is due to the change in the kinetic energy. Now the total energy decreases and the kinetic increases as we go inwards towards the nucleus, and we have the weird picture of the de Broglie frequency *increasing* from $f_{n'}$ to f_n while the atom is losing energy and radiating the frequency difference. Obviously this picture fails completely when we include elliptic orbits. But a more satisfactory reconciliation takes place if we equate E not to mc^2 but to mc^2+V where V is the potential energy. Then we have

$$f_n=\frac{m_0c^2}{h}\left(1+\frac{2\pi^2e^4}{n^2h^2c^2}\right)-\frac{4\pi^2m_0e^4}{n^2h^3},$$

neglecting small quantities. Now

$$f_{n'}-f_n=(2\pi^2m_0e^4/h^3)(1/n^2-1/n'^2).$$

This is the same expression as before except that now the de Broglie frequencies are reversed. As we go inward these frequencies decrease and the frequency radiated is equal to the *decrease* in the de Broglie frequencies.

That the argument quoted leads to the correct numerical frequency for the radiated photon is due to the fact that the kinetic energy in any circular orbit due to the usual law is half the negative potential energy. Hence if the kinetic energy is K the potential is $-2K$ and the total energy, $-K$. It results then that the difference of the kinetic energies in any two orbits is the negative of the difference of the total energy. Hence the foregoing agreement.

There may be no urgent reason for reconciling the de Broglie and the old Bohr pictures. But if reconciliation must be made it ought to be done with as small a punishment as possible to the processes of logic.

Newton's and Huygens' views of refraction

"To state the law of refraction in terms of the group velocity and wave velocity: In a vacuum the group velocity v and the wave velocity u are identical. Not so in a denser optical medium. We picture the photons of velocity v as attracted by the new medium; therefore v_2 in the new medium is greater than c in a vacuum. But on the wave theory u_2 is less than c, and we easily derive the law $\sin i/\sin r=c/u_2$. But since $u_2v_2=c^2$ we have $\sin i/\sin r=c/u_2=v_2/c$. Thus we may state the law of refraction either in terms of wave velocity or in terms of group velocity."

This argument suggests that the group velocity in a medium like carbon bisulphide is greater than that of light in a vacuum. For certainly $\sin i$ is greater than $\sin r$. Now Michelson measured directly the speed of light in carbon bisulphide and found it was equal to the speed in air divided by 1.758. But the index of refraction of the chief luminous part of the light he used was 1.64. The phase or wave velocity therefore was $3\times10^{10}/1.64$ cm·sec.$^{-1}$. From the data given on the dispersion of light in CS_2 Michelson computed the group velocity and found that it should be equal to $3\times10^{10}/1.75$ cm·sec.$^{-1}$. So it was clear that the velocity which he had measured was the group not the phase velocity.

Consequently we learn that the group velocity in carbon bisulphide is 7 percent less than the wave velocity and only about four-sevenths of the velocity in a vacuum. Hence the argument quoted is fallacious.

The fact is that the de Broglie scheme cannot be carried over into light. There is no characteristic connected with a beam of light that is propagated with a speed greater than that of light in a vacuum—except for the case which is frequently quoted, that of anomalous dispersion, and even here, on account of the influence of absorption in producing a variation of the characteristic, there is difficulty in attaching a meaning to the term velocity.

In the argument quoted, the relation $u_2v_2=c^2$ cannot in general be used even for corpuscles (electrons) as we pass from one medium to another. Ordinarily there would be a variation of potential energy which would modify that simple relation.

The two points of view regarding refraction, that of Newton and that of Huygens, may be brought together if we deal with the momentum of the photons on the one hand and, on the other, the velocity of the waves. For we take as experimentally established the relation for the pressure of light—that it is equal to the energy density in the (directed) beam. It follows at once that the momentum of a photon is equal to its energy hf divided by c, the velocity of light. A similar result follows from the Compton effect. We may then write $M=hf/c$, where M is the momentum of the photon. It is true that this relation may be claimed to have been proved only for the case of light in air (or vacuum). But for that case $M=hf/c=h/\lambda$. Different photons in air have momentums inversely proportional to their wave-lengths. But we may extend the relation to hold for different media. Then we state that the momentum of a photon increases as it passes from air to water not because the velocity increases but because the wave-length decreases. We then state the law of refraction to include both the wave and the photon points of view; namely, $\sin i/\sin r=c/u_2=M_2/M$.

The relation $M=h/\lambda$ follows from the relation for the momentum of radiation as given by Maxwell's theory, namely, that it is equal to the the energy per unit volume divided by the velocity of propagation. Here wave velocity only is thought of. Hence we arrive at the general law: The velocity of a photon is identical with that which we have associated with a wave motion of the corresponding wave-length of light.

A beam of light in water ought to exert a pressure of about four-thirds of that of a beam of equal intensity of light in air. But its accurate measurement would be difficult.

A Proposal for a Comprehensive Examination in Physics at the Baccalaureate Level

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THE American Association of Physics Teachers has during the last three years sponsored nation-wide examinations in college physics. These examinations have been given in approximately 500 different colleges in the United States and Canada, and from the results many important conclusions have been made. One of the most impressive of these is the fact that students demonstrating extremely high achievement may appear in the most remote and obscure college in the land. So obvious is this from the examination results that one is tempted to make the generalization that these outstanding students come so many per hundred thousand population, regardless of the teacher or college. These students are rare intellectual jewels, who with proper opportunity for polishing in our graduate colleges, will adorn our social order. No stone should be left unturned in the effort to make it possible for them to receive proper advanced training.

All agree that these students should be given opportunity for graduate training. At the present time, and under the present system of awarding scholarships and prizes, some of these fine intellects in obscure places are overlooked, and because of it our social order is the poorer. The

writer knows of one man, last known to be a truck driver, who stood a few years ago in the highest one-tenth of the highest percentile in a widely given Edison examination.

With the possibility of doing something constructive about this general situation, the Executive Committee of the American Association of Physics Teachers has been approached, as follows: *It is suggested that a nation-wide examination be set annually for those who are finishing college work for baccalaureate degrees with a major in physics.*

It is asserted that such an examination would serve as follows:

1. Teachers of college physics recognize that the ablest minds with which they come in contact usually stand out clearly ahead of the pack. These unusual minds may appear in obscure places. They are so rare and so valuable that it is imperative that they be saved for science. The examination suggested would definitely locate these minds.

2. Regardless of the subject chosen, every nation-wide testing program carried out to date has shown that there exist as great individual differences between colleges as between students. The high five percent of the seniors graduating from College A may average no better in subject matter achievement than the best in the low quarter in College B. At the present time officials administering graduate educational subsidies have few and imperfect means of distinguishing between seniors from various colleges applying for such subsidies. The examination suggested would give graduate college administrators objective, reliable evidence to be used with other criteria in granting educational subsidies.

3. Men trained in physics, who expect to enter industry, would find it greatly to their advantage to be able to point to objective evidence of meritorious achievement as indicated by the results of the examination suggested. The examination would also indicate in which division of physics a student had the greatest strength; this would give the executive in industry first-hand objective evidence on which to base his decision to employ or, having employed, to make an intelligent assignment of work to the new employee.

4. The knowledge that at the end of his college career he would have an opportunity to register his grasp of the whole field of physics would favorably motivate a student during his college career. Harvard University has given comprehensive examinations since 1919. In the last twelve years the honor graduates from that institution have increased from 21.6 to 37 percent. Dean A. C. Hanford is quoted by the Associated Press, October 17, 1936, as saying, "The general examinations have not only provided a means of testing the student's grasp or mastery of his major field as a whole instead of as a series of courses or credits accumulated one by one, kept in water-tight compartments, and more or less forgotten as each course is passed, but they have also set up a distant goal toward which the student moves during his three upper years and which serves to motivate his work over that period."

5. Comprehensive examinations in physics would stimulate college teaching in physics for two reasons: first, the curriculum would be thought of and treated as a whole; and second, in obscure colleges both the professors and students would know that genuine merit in physics would have an opportunity to be recognized.

6. Physics needs to be recognized by the public as a profession. Examinations as suggested should help to give greater professional standing to physicists.

The following suggestions are offered as tenative proposals:

1. The examinations would be given in January of each year.

2. They would be offered simultaneously at various places in the United States and administered by responsible parties, under prescribed conditions, for two days.

3. A battery of seven examinations in mechanics, sound and acoustics, electricity and magnetism, heat, light and optics, modern physics, and general physics, would be offered the first year.

4. Each examination would be two hours in length.

5. Each examination would be independent of all the others in the battery and would be constructed by a special committee.

6. The committee constructing the examination would be responsible for its grading. One person would grade all the answers to a given question.

7. The cost of taking the examinations would be a minimum of two dollars for four subjects and a fee of fifty cents extra for each subject above that number.

8. Each individual writing the examinations would be given a statement of his percentile rating in each test taken.

Discussion of this proposal is invited.

Report of the Committee on Mathematical Preparation of Students and Mathematical Prerequisites

COPIES of the fourth report of the A.A.P.T. committee on "Mathematical Preparation of Students and Mathematical Prerequisites for the General Physics Course" may be had from Professor T. D. Cope, Randal Morgan Laboratory, University of Pennsylvania, Philadelphia.

The Solution of $\nabla^2\varphi-(1/c^2)\partial^2\varphi/\partial t^2=-\alpha$

W. F. G. Swann

Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania

PERHAPS some apology seems necessary for giving a new method of arriving at the solution of the above equation whose solution is so well known. However, it is the experience of the writer that the usual forms of solution have in them certain elements which appear somewhat artificial to many physicists; and, for this reason a solution which proceeds in a straightforward manner may be of service.[1]

Starting then with the equation

$$\partial^2\varphi/\partial x^2+\partial^2\varphi/\partial y^2+\partial^2\varphi/\partial z^2 -(1/c^2)\partial^2\varphi/\partial t^2=-\alpha, \quad (1)$$

we make the transformation

$$\xi=x,\quad \eta=y,\quad \zeta=z,\quad \rho=r,\quad \tau=t\mp r/c, \quad (2)$$

where $r^2\equiv x^2+y^2+z^2$. We then find, immediately,

$$\frac{\partial}{\partial x}=\frac{\partial}{\partial\xi}\mp\frac{1}{c}\left(\frac{\partial r}{\partial x}\right)\frac{\partial}{\partial\tau}=\frac{\partial}{\partial\xi}\mp\frac{x}{rc}\frac{\partial}{\partial\tau}=\frac{\partial}{\partial\xi}\mp\frac{\xi}{\rho c}\frac{\partial}{\partial\tau}.$$

Analogous results hold for $\partial/\partial y$ and $\partial/\partial z$, so that

$$\frac{\partial}{\partial x}=\frac{\partial}{\partial\xi}\mp\frac{\xi}{\rho c}\frac{\partial}{\partial\tau};\quad \frac{\partial}{\partial y}=\frac{\partial}{\partial\eta}\mp\frac{\eta}{\rho c}\frac{\partial}{\partial\tau};$$
$$\frac{\partial}{\partial z}=\frac{\partial}{\partial\zeta}\mp\frac{\zeta}{\rho c}\frac{\partial}{\partial\tau};\quad \text{also } \partial/\partial t=\partial/\partial\tau. \quad (3)$$

Thus

$$\frac{\partial^2\varphi}{\partial x^2}=\frac{\partial^2\varphi}{\partial\xi^2}+\left(\frac{\xi}{\rho c}\right)^2\frac{\partial^2\varphi}{\partial\tau^2}\mp\frac{1}{c}\left(\frac{\partial}{\partial\xi}\left\{\frac{\xi}{\rho}\frac{\partial\varphi}{\partial\tau}\right\}+\frac{\xi}{\rho}\frac{\partial^2\varphi}{\partial\tau\partial\xi}\right). \quad (4)$$

Denoting the last expression in parenthesis by $(\ )_\xi$, and the corresponding parentheses in the expressions for $\partial^2/\partial y^2$ and $\partial^2/\partial z^2$ by $(\ )_\eta$ and $(\ )_\zeta$, respectively; and, observing further that $\partial/\partial\tau=\partial/\partial t$, and that $\xi^2+\eta^2+\zeta^2=\rho^2$, we have, from Eq. (4) and its companions in y and z,

$$\{\nabla^2\varphi\}_{xyzt}=\{\nabla^2\varphi\}_{\xi\eta\zeta\tau}+\frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2}\mp\frac{1}{c}\{(\ )_\xi+(\ )_\eta+(\ )_\zeta\}, \quad (5)$$

where the subscripts to $\nabla^2\varphi$ denote the variables in terms of which ∇^2 is expressed. Thus, from Eqs. (1) and (5),

$$-\alpha=\{\nabla^2\varphi\}_{xyzt}-\frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2}$$
$$=\{\nabla^2\varphi\}_{\xi\eta\zeta\tau}\mp\frac{1}{c}\{(\ )_\xi+(\ )_\eta+(\ )_\zeta\}. \quad (6)$$

Let us seek the value of φ at the origin in the ξ, η, ζ, τ system, and let us surround the origin with a small sphere, which shall form part of the boundary, the main boundary being elsewhere.

Now Green's theorem, in three dimensions, is applicable as well in the ξ, η, ζ, dimensions of the group ξ, η, ζ, τ, as it is applicable in the x, y, z, dimensions of the group x, y, z, t. In one of its well-known forms,

$$\iiint\left[\varphi\nabla^2\left\{\frac{1}{\rho}\right\}_{\xi\eta\zeta\tau}-\frac{1}{\rho}\{\nabla^2\varphi\}_{\xi\eta\zeta\tau}\right]d\xi d\eta d\zeta +\iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N}-\varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\right\}d\sigma=0.$$

Since $\nabla^2(1/\rho)=0$, we have, using Eq. (6),

$$\iiint\frac{\alpha}{\rho}d\xi d\eta d\zeta \mp\frac{1}{c}\iiint\frac{\{(\ )_\xi+(\ )_\eta+(\ )_\zeta\}}{\rho}d\xi d\eta d\zeta +\iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N}-\varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\right\}d\sigma=0. \quad (7)$$

Now

[1] The solution usually given is that of G. Kirchhoff, Berl. Sitz., 641 (1882). Another proof has been given by Max Mason, Phys. Rev. **15**, 312 (1920). The proof now given was developed by the writer for use in his classes on electrodynamics. As it is on the point of being submitted for publication, another proof following different lines has made its appearance; see S. Ballantine, J. Frank. Inst. **221**, 469 (1936).

$$\frac{(\ )_\xi}{\rho}=\frac{1}{\rho}\left[\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho}\frac{\partial\varphi}{\partial\tau}\right)+\frac{\xi}{\rho}\frac{\partial}{\partial\tau}\left(\frac{\partial\varphi}{\partial\xi}\right)\right]$$

$$=\frac{1}{\rho}\left[\frac{\partial\varphi}{\partial\tau}\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho}\right)+\frac{2\xi}{\rho}\frac{\partial}{\partial\tau}\left(\frac{\partial\varphi}{\partial\xi}\right)\right].$$

Noting that $\partial\rho/\partial\xi=\xi/\rho$, we find immediately

$$\frac{(\ )_\xi}{\rho}=\frac{\partial\varphi}{\partial\tau}\left(\frac{3\xi^2}{\rho^4}-\frac{1}{\rho^2}\right)+2\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right).$$

Analogous expressions hold for $(\ )_\eta/\rho$ and $(\ )_\zeta/\rho$, so that, since $\xi^2+\eta^2+\zeta^2=\rho^2$, the integrand in the second integral of Eq. (7) becomes

$$\frac{\partial\varphi}{\partial\tau}\left(\frac{3\rho^2}{\rho^4}-\frac{3}{\rho^2}\right)+2\left\{\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)+\frac{\partial}{\partial\eta}\left(\frac{\eta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)+\frac{\partial}{\partial\zeta}\left(\frac{\zeta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right\}=2\left\{\frac{\partial}{\partial\xi}\left(\frac{\xi}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)+\frac{\partial}{\partial\eta}\left(\frac{\eta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)+\frac{\partial}{\partial\zeta}\left(\frac{\zeta}{\rho^2}\frac{\partial\varphi}{\partial\tau}\right)\right\}. \quad (8)$$

On substituting this in Eq. (7), and converting the corresponding volume integral to a surface integral, we have

$$\iiint\frac{\alpha}{\rho}d\xi d\eta d\zeta+\iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N}-\varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\mp\frac{2\cos\theta}{c\rho}\frac{\partial\varphi}{\partial\tau}\right\}d\sigma=0, \quad (9)$$

when θ is the angle between the outwardly drawn normal to the surface and the radius vector drawn from the origin at which φ is sought.

Now, in the contribution to the surface integral by the little sphere we have, in the limit, zero from $(1/\rho)\partial\varphi/\partial N$ and from $\mp(2\cos\theta/c\rho)\partial\varphi/\partial\tau$. The term $-\varphi(\partial/\partial N)(1/\rho)$ contributes $-4\pi\varphi$. Thus, with the surface integral now applying to the main boundary, Eq. (9) yields

$$4\pi\varphi=\iiint\frac{\alpha}{\rho}d\xi d\eta d\zeta+\iint\left\{\frac{1}{\rho}\frac{\partial\varphi}{\partial N}-\varphi\frac{\partial}{\partial N}\left(\frac{1}{\rho}\right)\mp\frac{2\cos\theta}{c\rho}\frac{\partial\varphi}{\partial\tau}\right\}d\sigma.$$

Here the integrals are taken at constant τ and $\partial/\partial N$ refers to differentiation along the normal in the coordinate system ξ, η, ζ, τ. Let us change to the variables x, y, z, t. Then $\partial/\partial\tau=\partial/\partial t$; and, if λ, μ, ν, are the directional cosines of the outwardly drawn normal to the surface,

$$\partial\varphi/\partial N=\lambda\partial\varphi/\partial\xi+\mu\partial\varphi/\partial\eta+\nu\partial\varphi/\partial\zeta,$$

so that from Eq. (3),

$$\frac{\partial\varphi}{\partial N}=\lambda\frac{\partial\varphi}{\partial x}+\mu\frac{\partial\varphi}{\partial y}+\nu\frac{\partial\varphi}{\partial z}\pm\frac{1}{c}\left\{\frac{\lambda\xi}{\rho}+\frac{\mu\eta}{\rho}+\frac{\nu\zeta}{\rho}\right\}\frac{\partial\varphi}{\partial\tau}$$

$$=\frac{\partial\varphi}{\partial n}\pm\frac{\cos\theta}{cr}\frac{\partial\varphi}{\partial t},$$

where $\partial/\partial n$ refers to differentiation along the normal in the coordinate system x, y, z, t. Thus

$$4\pi\varphi=\iiint\frac{[\alpha]}{r}dxdydz+\iint\left\{\frac{1}{r}\left[\frac{\partial\varphi}{\partial n}\right]-[\varphi]\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\mp\frac{\cos\theta}{r}\left[\frac{\partial\varphi}{\partial t}\right]\right\}dS, \quad (10)$$

which is the solution sought, and where if t is the time at which φ is sought at the origin, the understanding is that the quantities in square brackets are to be evaluated at $t=r/c$ if the minus sign is used in the last term of Eq. (10), or at $t=-r/c$ if the plus sign is used.

Reprints of Survey Articles for Class Use

Reprints of Dr. Harvey L. Curtis' article on "Principles Involved in Determining the Absolute Values of the Electrical Units" may be obtained at cost from the Editor. The cost of 6 reprints is 50 cts. postpaid.

The First Lectures in College Physics

Alfred H. Weber
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MOST of us find it difficult to begin a task. Once started, we usually make progress with an ease considerably greater than was anticipated in our mental estimate of the undertaking before us. There is a "work function," shall we say, associated with the initiation of each new venture. Particularly does such a "potential barrier" exist in the minds of many of our college students coming to their first lectures in general physics. The magnitude of this work function varies of course with each individual. For some of the students it has the normal value naturally accompanying the beginning of a new study. For others, it has an unusually high value, a condition due in some cases to previous training in which investigation of physical science occupied a minor place. In either case, effort should be made to reduce the work function.

The difficulties encountered in introducing the newcomer to physical science are partly subjective and partly objective. Subjectively, a number of the students in the first course in physics lack interest in the science. Objectively, the matter traditionally presented in the first lectures in college physics is not nearly so attractive as is a large portion of the later material. There is much that we can do to improve the interest content of this introductory matter. And, parenthetically, we can at the same time modestly advertise (an objectionable word for a quite laudable idea) our science. Paul D. Foote[1] has spoken some well chosen words on this score on the occasion of his retirement from the presidency of the American Physical Society.

It is suggested, therefore, that the first lecture hours be devoted to building up student interest rather than to the elements of kinematics and dynamics with their burden of logic. In so doing we cannot of course shirk the obligation of presenting essential introductory notions. This twofold end can be accomplished by weaving into the fabric of our introductory lectures some of the main features of what is commonly termed "modern physics." The attention that modern physics has won from the general public is convincing proof of its fascination.

Let us consider in more detail how this idea is to be evolved in practice. We may begin our course by spending a few minutes on a running history of chemistry and physics, pointing out how widely divergent these sciences were in their infancy and how very intimate they have become in more mature life. By this procedure the way can be prepared in an easy and interesting manner for a definition of physics. The exact words used to define the science will vary with each group and each teacher. Perhaps a purely descriptive definition will suffice. At any rate, the definition should specify the general subject material of physics and its particular viewpoint—matter, the body of physics, and energy, its soul. Following this, it will be found stimulating to inject questions of a fundamental character such as the nature of matter and energy. Almost unconsciously the class can be led by the skillful teacher into an informal discussion of the atomic-molecular theory of matter and the electron theory. An excellent guide as to just what to consider here may be found in the second chapter (brought up to date) of Chaffee's book on thermionic vacuum tubes.[2] This advances the group to the point where it is ready for some comments about the Bohr theory. The hydrogen atom is naturally the model for illustration. Some important constants, such as the mass of the hydrogen atom and the relative masses of the nucleus and electron which compose it, should be given. While discussing these data such "routine" details as the expression of very large and very small numbers in powers of 10 and the eventual necessity for distinguishing between mass and weight can be included opportunely in the lecture. Next, some little time should be given to the ultimate particles—the electron, the proton, the neutron and the positron. The desirable historical note is added by reference to the comparatively recent work of Chadwick, the

[1] R. S. I. 5, 2, 57–66 (1934).

[2] *Theory of Thermionic Vacuum Tubes*, pp. 17–25.

Joliots, and Anderson on the last two of these.[3] W. V. Houston's survey article[4] also contains suggestive material. Turning now from matter to energy, a few deft historical touches, dealing with the span from Newton and Huygens to Planck and Schrödinger, can be used to present the question of whether light be waves or particles or both.

In this way the class early comes to be aware of the problems of the constitution of matter and the nature of radiant energy. Most textbooks either omit this material or include it in later chapters. The suggestion here given of mentioning these fundamental questions in the beginning lectures need only be tried to demonstrate its value. If it is possible at all to arouse a student's interest, it can be done by giving him these inspiring glimpses of what we may rightly term the romance of physical science.

There remains another duty for the first lectures: to exorcise from the student's mind the evil spirit who plagues him with the thought that one must be something of a mathematical genius even to commence the study of physical science. To eradicate the feeling of mathematical helplessness, nothing is quite so effective as to summarize briefly the simple mathematics required. This can be done in a space of time that astonishes the student with its brevity. Such a mathematical summary, clinched by the assignment of several good problems, breeds self-confidence in the student. The writer usually assigns as a first problem one designed to renew the student's knowledge of logarithms or to introduce the slide rule. A formula, such as that used in the determination of Young's modulus by the optical lever method, is given to the student together with data obtained in the very laboratory where he is soon to work. The student is then required to calculate values for Young's modulus with the help of logarithms or the slide rule. Such problems afford some exercise in computation, correlate the lecture and laboratory work in a way that has a direct appeal to the student and give practice in the concise method of expressing large numbers in powers of 10.

Two points have been stressed here—the reduction of the work function of beginners by including with the ordinary routine material some of the outstanding features of the two major problems of modern physics, and the statement of the mathematical prerequisities of the course in the simplest possible manner, followed by the assignment of real laboratory problems. All of this introductory material will be found to require from three to four hours of lecture and quiz. It is our experience that it is time very profitably spent.

[3] See particularly C. D. Anderson's original papers: Science **76**, 238 (1932); Phy. Rev. **43**, 491 (1933).
[4] Am. Phys. Teacher **2**, 53 (1934).

Durham-Chapel Hill Meeting of the American Physical Society and The American Association of Physics Teachers, February 19–20, 1937

THE American Association of Physics Teachers has accepted the invitation from the American Physical Society to sponsor a half-day's program at the meetings of the American Physical Society to be held at Duke University and the University of North Carolina, February 19–20, 1937, under the auspices of the Southeastern Section of the Society.

By vote of the Executive Committee of the Association, it was decided that the session sponsored by the Association should comprise three invited papers. Accordingly, the following program has been prepared for Saturday morning, February 20:

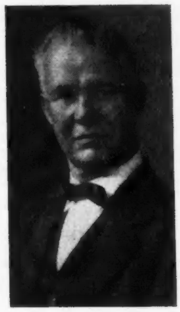
Some Aspects of Physics Teaching in the South. L. L. HENDREN, *University of Georgia.*

What College Physics Expects of Pre-College Education. THOMAS D COPE, *University of Pennsylvania.*

Graduate Training for a Career in Physics. G. P. HARNWELL, *Princeton University.*

Contributed papers having to do with the teaching of physics will be included in the sessions sponsored jointly by the American Physical Society and the Southeastern Section. The three sessions under this joint sponsorship will include two symposiums, on some branches of applied and of pure physics, and the usual ten-minute contributed papers. There will be a dinner on Friday evening, February 19, after which Dean George B. Pegram of Columbia University will speak. The Washington Duke Hotel in Durham has been selected for headquarters; the rate for a single room is $2.50 per day.

William Suddards Franklin, 1863-1930



First Recipient of the Award for Notable Contributions to the Teaching of Physics

The American Association of Physics Teachers has made the first of its annual Awards for Notable Contributions to the Teaching of Physics to William Suddards Franklin, posthumously, and has placed bronze memorial tablets in the physics laboratories of Lehigh University and of Massachusetts Institute of Technology in commemoration of him and his work. The presentation was made by Professor D. L. Webster, President of the Association, and Professor Frederic Palmer, Jr., Chairman of the Committee on Awards, during the annual joint banquet of the Association and the American Physical Society at Atlantic City, December 29, 1936. The certificate of award was received by Professor Franklin's son, Mr. Curtis Franklin, of New York City. Professor Bidwell, of Lehigh University, and Dean Goodwin, of Massachusetts Institute of Technology, accepted the memorial tablets on behalf of their institutions.

Address by President Webster

The American Association of Physics Teachers' Award for Notable Contributions to the Teaching of Physics is not only new, but of a new kind. All of us who are teachers have felt rewarded for our services in the teaching of physics before this, and often very well rewarded, but in different ways. Our salaries are one form of reward—prosaic, but highly practical. We also have had the more inspiring forms of reward that come from good work—the satisfaction of seeing the results, and what is more important, of knowing that we are doing our best for a thoroughly worthy cause.

These forms of reward are found in research as well as in teaching. In research there are also special honors and prizes that range all the way up to the Nobel Prize. In teaching, however, there have been relatively few such honors.

The reason for this difference is primarily historical. Research, in this country, is no older than many of us, but teaching has gone on for centuries. Teaching was long recognized as a necessary art, essential to civilization and therefore laudable; so laudable, in fact, that the teacher, like the minister, was assumed to be rewarded so much by the satisfaction of doing his best for such a cause that he needed little of the other rewards. Meanwhile, two or three generations ago, research was an idiosyncracy and the few research workers we had were not understood. Then came the realization that research was also laudable. Time was allowed for it in a professor's schedule, and money was allowed for apparatus. The stimulation of research was carried on by every means, including honors.

That movement has been good—very good. But even so, it has its dangers. The statement that no man can serve two masters applies to research and teaching, as I know well from having tried to serve them both. If a research problem is as exciting as it ought to be, you are sure to neglect your teaching, and all too liable to begrudge the time you are obliged to put on it, and therefore to dislike it. On the other hand, in some other year you can get just as excited about a new idea for teaching, and the only way to hold

to that adequately is to let your research apparatus drop into the category of things that moth and rust corrupt. "Routine teaching" can be done along with good research, or a limited program of research along with serious, original work to improve teaching; but you cannot serve these two masters both really well at the same time.

If you do serve one at one time and the other at another time, however, you soon come to the conclusion that they are just about equally hard masters. In the improvement of teaching, you have to use the same logical powers as in research, and the same creative imagination—here I am speaking of research along new lines and of teaching with real new ideas in it; the same creative imagination is needed for both. In addition, the teacher must have human understanding which has no counterpart in research. If research deserves special honors, teaching deserves them as much or even more.

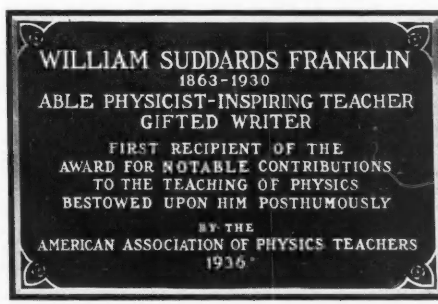
It is with great satisfaction, therefore, that we can now view the establishment of an annual award, made possible by an anonymous donor, for notable contributions to the teaching of physics. It will not be a monetary award, because the value of the service for which it is given is so far out of proportion to any funds at hand, even with our donor's generosity, that such an award would tend more to belittle than to exalt the service. Neither is it the intention of the donor or of the Association to make this award an object of competition. Whatever may or may not be said of prizes for research and of the difficulty of judging the relative merits of researches in different fields, far more may be said of the difficulty of judging teachers; human judgment is too fallible in such matters for any man or any committee to presume to judge such a competition. It would be even more inappropriate for any person receiving an award in this field to consider himself thereby designated as the winner of such a competition.

On the contrary, the recipient of this award is designated as a representative of an ideal—the ideal of the great teacher. The purpose of the award is to hold this ideal before us, to remind us of a teacher who has gone far toward it, and to say to each one of us, "Go, thou, and do likewise."

Address by Professor Palmer

The committee charged with the duty of selecting a recipient for this award begs to report that it has chosen that one of our contemporaries who, in its judgment, most completely represents the ideal just described by Professor Webster. Hence, it recommends that the award be made, posthumously, to *William Suddards Franklin*, professor of physics, successively, at the University of Kansas, Iowa State College, Lehigh University, Massachusetts Institute of Technology, and Rollins College, in recognition of the many contributions which he made through the brilliant clarity of his writing and through the stimulating magnetism of his speech to the advancement of the art and practice of physics teaching.

Franklin was born at Geary City, Kansas, on October 27, 1863. His early education was obtained in the local schools supplemented by that which he gained at first hand in the crude laboratory of physics and chemistry equipped by himself and his brother, Edward, in the cellar of their father's house. Upon applying for admission to the University of Kansas in 1883, Franklin asked to be examined in physics. As a result of the work in his home laboratory he passed brilliantly all of



Photograph of one of the memorial tablets. These tablets will be erected at Lehigh University and at Massachusetts Institute of Technology.

the examinations given him and hence, upon entering the university as a freshman, received the standing of a *graduate student* in physics. His command of mathematics was such that during his *freshman* year he was admitted to classes in sophomore, junior and senior mathematics, and led them all. Thus it is not strange that before the end of his third year as an undergraduate he had

acquired the duties, if not the title, of instructor in physics, and upon graduation was immediately appointed assistant professor for three years. At the end of this period he studied for a year under Planck at the University of Berlin and then returned home to hold the Morgan Fellowship at Harvard for one year. There followed professorships of physics, sometimes combined with electrical engineering, at Iowa State College, for five years; at Lehigh University, for eighteen years; and at Massachusetts Institute of Technology, for twelve years. He had taught for only one year at Rollins College when he met with an automobile accident which resulted in his untimely death on June 6th, 1930.

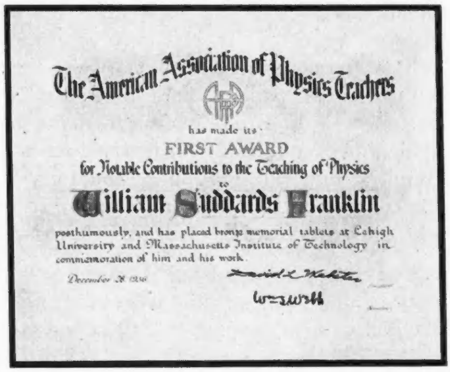
In the early days Franklin contributed a number of papers to the scientific journals, but later he devoted much time to the writing and publication of textbooks, some twenty-five volumes, often in collaboration with another author. One of his collaborators says that in these cooperative undertakings it was Franklin who did the lion's share of work, took the *entire* risk of financial failure, but always shared the fruits of financial success. Franklin's writing was never stereotyped or conventional. Every page was alive. When a teacher disapproved of using one of Franklin's books as a class text because of the informality of its style, that same teacher invariably read the book himself because he found in it fresh treatment of old topics, and clear concepts to replace his own hazy notions. Franklin was not only alive to the clarification and vitalization of his subject matter, but he was conscious of the teacher who might use his book as a text, and hence wrote in such a manner as to inspire the reader with his own attitude toward teaching.

What was that attitude? Students who came into classroom contact with his dynamic personality were quick to discover it. Franklin himself describes it thus:

"I know from experience that most of our students like physics when the teaching is directed insistently towards the development and use of precise ideas or towards what may be called training in analytic thinking; and I know that our students can be carried far in this mildly difficult but highly profitable business. In fact, I have always found my students to be so eager and enthusiastic that I could not wish them to be more eager or more enthusiastic. . . . An almost purely analytical course in elementary physics arouses intense interest if one heeds Bacon's admonition and connects every detail of analytic method with actual conditions and things."

Again he writes:

"Most of my life has been spent as a teacher in a technical school, and teaching is great fun in spite of, or, I should say, in all honesty, partly because of delinquent students and their softened fathers and tearful mothers."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Certificate of award presented to the family of Professor Franklin.

In a little collection of essays dealing with the beauties of nature and their effect upon the education of youth—a collection entitled, *Bill's School and Mine*—Franklin says:

"The author, a teacher, has never yet been helped by anything he has ever read in pedagogy—and yet he writes a book of educational essays! Teaching has always been to the author the greatest of fun, but he despises pretentious philosophy."

It is interesting to know that, largely due to the influence of these essays, the city of South Bethlehem, Pennsylvania, established a recreation park for the youth of the city and named it "Franklin Park." When notified of this at his Massachusetts residence, Franklin was overjoyed and exclaimed to one of his colleagues: "That park was not named after *Benjamin* Franklin, either!"

The exuberant energy of this man who boasted that the teaching of physics was the greatest fun in the world found an outlet in the Society for the Promotion of Engineering Education; for, to him, physics was the soul of engineering. Hence, he

became an enthusiastic worker for the cause of science teaching, through membership in that Society.

Franklin's colleagues say that no member of his department was more stimulating of research among students—an influence which he carried over into the broader field of the American Physical Society. None of us who were privileged to attend meetings of the Society for the first twenty-five years of its existence can forget Franklin's frequent keen and clarifying comments upon the papers there presented. No matter how well the author had set forth his case, Franklin always could add, during the discussion, some enlightening information, or could crystallize the content of the whole paper in one or two well-chosen sentences. His passages at arms with Arthur Gordon Webster were not merely thrilling at the moment, but thought-provoking later in the privacy of one's study.

The committee recommends that, upon this occasion, the award be made in the form of a certificate to the family of Professor Franklin, and two suitably inscribed bronze tablets in his memory, one to Lehigh University, and one to Massachusetts Institute of Technology.

Thus, Mr. President, it is our belief that in honoring the memory of William Suddards Franklin we are recognizing those qualities in him which made him a great teacher of physics—those qualities which it was intended should receive recognition through the creation of this Award for Notable Contributions to the Teaching of Physics.

Appointment Service

Representatives of departments or of institutions having vacancies are urged to write to the Editor for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

8. Man, 36, married. 15 yr. teaching experience in two eastern universities. Completing Ph.D. thesis in spectroscopy this year at Cornell. Undergraduate teaching experience: demonstration lectures, premedical physics, optics, atomic physics, astronomy, astrophysics.

9. Ph.D. Univ. of Minnesota; S.B., S.M., M. I. T.; 1 yr. grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yr. teaching experience in universities, colleges and technical schools, including 10 yr. head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

10. M.S., B.S. Louisiana State Univ.; 3 yr. graduate work, Cornell; doctorate almost completed. Research in spectroscopy. Age 28, unmarried. 4 yr. instructor, Louisiana. Special interest in teaching and in developing demonstration and laboratory experiments.

12. Ph.D. Cornell, B.S. Bowdoin College. Age 38, married. 11 yr. teaching in both men's and women's colleges in East and South. Research in electron physics. Special interest in development of demonstration lectures, laboratory experiments and equipment. Glass blowing.

13. Ph.D. Cornell. Age 31, married, 2 children. 4 yr. college teaching, 5 yr. full-time research in x-rays. Primarily interested in college teaching and research. Hobbies: photography, geology, music.

14. Ph.D. Chicago, B.S. Bradley Polytechnic, with minors in math. and chem. Age 25, married. 4 yr. laboratory and teaching assistant, Chicago. Research, Faraday effect at high frequencies.

15. Ph.D. Iowa State, B.S. in E.E. Minnesota. Age 33, unmarried. 5 yr. sales and research engineer, 4 yr. teaching fellow, physics. Research, effect of gas on metal surfaces used for electron recording, etc. Interested in teaching.

16. Ph.D. Indiana. Age 38, married, 2 children. 6 yr. college teaching. Research in acoustics. Trained for teachers college or university position. Interested in teaching, laboratory development, and research.

17. Man, age 39, married, 1 child, Protestant. Ph.D. Univ. of Pittsburgh. 14 yr. teaching undergraduate physics; 5 yr. asst. prof., important eastern university. Desires professorship in medium sized progressive college; available fall 1937.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

Exhibition of Scientific and Applied Photography

The Photographic Society of America is holding an Exhibition of Scientific and Applied Photography in Rochester, March 15–April 2. This exhibition will contain prints and photographic apparatus classified in ten sections. The closing date for entries is February 15. For further information, address C. B. Neblette, Secretary, Rochester, New York.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

Characteristic Curves of Glow Discharges in Air

J. B. NATHANSON
Department of Physics, Carnegie Institute of Technology, Pittsburgh, Pennsylvania

THE study of electrical glow discharges in gases has been confined in the past, mainly to first year graduate courses. Of late years, due to the tremendous strides made in the practical applications of the theory of the flow of electricity in gases, interest in these phenomena has grown to such an extent, that the study of them has been made a part of advanced undergraduate courses. It has been generally customary to study the appearance and the sizes of the various light and dark portions of the glow discharge as functions of the gas pressure and of the distance between the electrodes. This distance is varied by mounting one of the electrodes on a movable iron shoe which can be operated from the outside by means of a suitable electromagnet. The discharge is generally actuated by an induction coil which serves satisfactorily for the foregoing observations, but not for the study of the voltage-current relationship of the glow discharge, due to the erratic and unsteady type of electrical discharge produced. In this paper is described a convenient arrangement for studying the characteristic curves of glow discharges in air. It has been used successfully by our advanced undergraduate students in physics, chemistry, and electrical engineering.

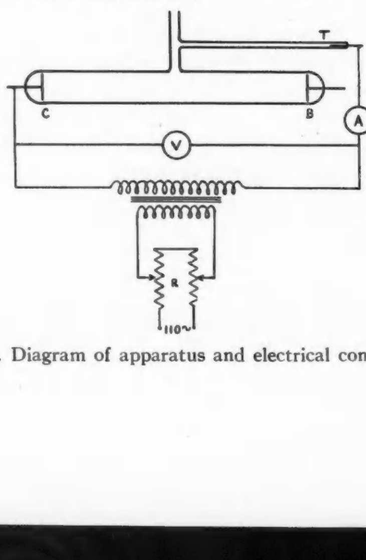

FIG. 1. Diagram of apparatus and electrical connections.

The apparatus is shown in Fig. 1. The glow discharge is produced by a small neon sign transformer, capable of supplying several milliamperes of current at voltages up to 10^4 volts. In order to render the discharge unidirectional, advantage is taken of the rectifying action of two electrodes within a gas, one of which is very small compared to the other, and forms the anode. A narrow side tube T, about 8 mm in diameter and 25 cm long, is attached to the customary two-electrode tube BC, used to demonstrate glow discharges in rarified gases. The main tube is about 40 cm long and 5 cm in diameter. A short tungsten wire, B & S gauge No. 26, is sealed in at the end of the tube T. Due to a smaller loss by sputtering, tungsten is preferable to platinum.

As is evident from Fig. 1, C will always form the cathode. A double sliding rheostat R, of about 100 ohms resistance and 3–4 amp. current capacity, is connected directly to the mains of a 110-v a.c. circuit. By varying the positions of the sliding contacts of the rheostat, any voltage from zero to 110 can be applied to the primary of the transformer. An electrostatic voltmeter reading up to 10^4 volts is placed between the electrodes C and T, while a d.c. milliammeter serves to measure the current. For pressures above 2 mm of mercury a closed manometer may be used, while a McLeod gauge serves to measure lower pressures. The discharge current was found to be fairly constant, so that the meters could be read with comparative ease, which could not be done when using an induction coil. This constancy also facilitates the observation of the characteristic appearance and the measurement of the thicknesses of the Crookes' dark space and the negative glow at low pressures.

The continuous curves of Fig. 2 show the

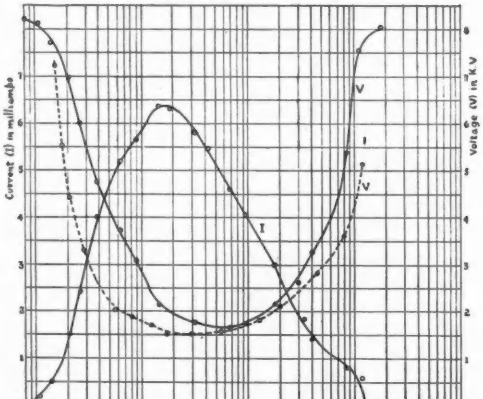

FIG. 2. Effects of pressure on the current and voltage.

variation with air pressure of the discharge current I, and voltage V, when the sliding contacts of the rheostat are held fixed during the evacuation of the air from the discharge tube. The dashed curve shows the variation of the voltage with pressure when the discharge current is maintained constant at 1.5 milliamp. during the evacuation of the air. For convenience of plotting, the pressures are plotted on a logarithmic scale, for as is well known, the maximum current and the minimum voltage occur at relatively low pressures.

In Fig. 3 are shown the results of plotting voltage *versus* current for variously maintained gas pressures, the values of which are indicated on the curves. For pressures above 1 mm, except for the initial rise in voltage, the curves show a falling characteristic. For these relatively high pressures, the negative glow is very brilliant and covers only a part of the area of the cathode, so that the falling characteristic is to be ascribed to the existence of the normal cathode fall of potential.[1] A rising characteristic at these higher pressures would doubtless be obtained if

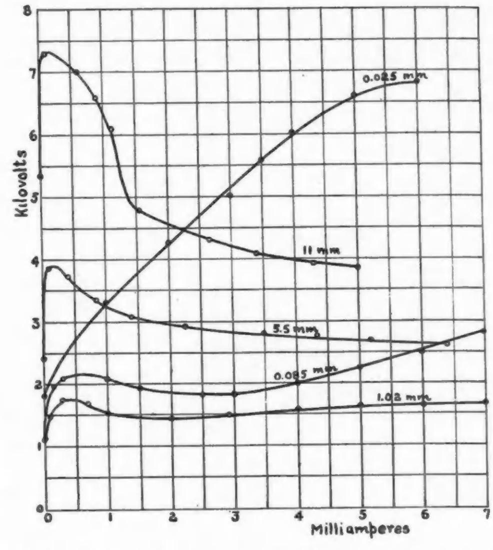

FIG. 3. Voltage *vs.* current, for various gas pressures.

the current could be increased sufficiently to cover all of the cathode with the negative glow, when the abnormal fall of potential would be developed. There is a limit to the magnitude of the current available, determined in part by the transformer characteristics and in part by the current capacity of the wire anode T. This wire becomes incandescent when too much energy is dissipated in the discharge tube.

At pressures below 1 mm, the entire cathode becomes covered with the negative glow for all values of the current, so that the abnormal cathode fall of potential is developed. This involves a rising voltage-current characteristic, as is illustrated by the curves in Fig. 3 for pressures of 0.085 mm and 0.025 mm. The rising characteristic becomes more pronounced as the pressure decreases. It is also interesting to note that for pressures in the neighborhood of 1 mm, the voltage is approximately constant with variation in current, a characteristic which has been applied in practice to the construction of voltage regulator tubes.

[1] Wien-Harms, *Handbuch der Experimental Physik*, Vol. 13, Part 3; Geiger and Scheel, *Handbuch der Physik*, Vol. 14, p. 175.

Mathematics are a species of Frenchmen; if you say something to them, they translate it into their own language, and presto! it is something entirely different.—GOETHE.

Inductance in the Elementary Laboratory

Roscoe E. Harris
Department of Physics, Lake Forest College, Lake Forest, Illinois

An experiment in elementary physics should clarify some important definition or law, or make some application of physics more obvious. Precision and technic, while valuable, do not appear to be as desirable ends in themselves as they once were.

Thus the experiment on the coefficient of self-inductance as usually presented by some type of bridge with complicated analysis is not very direct. Such an experiment may have value in developing ability to follow an elaborate electrical hook-up and a few students may profit by it, but it seems that the main purpose of an essential experiment—the clarification of physical facts—is lacking. In considering the attributes of self-inductance that are essential, its effects upon an alternating current seem important. While the determination of the coefficient does not follow directly from its definition, the impedance equation is no more difficult than the usual bridge analysis and has an important application in itself. Two experiments have been found useful in this laboratory.

Exp. 1. *An inductive circuit offers a greater resistance to alternating current than to direct current.* The impedance is found by alternating current voltmeter-ammeter measurements, the resistance by direct current measurements; and the coefficient of self-inductance then is determined. The presence of iron in the circuit is observed. The changed impedance in the primary, when the secondary of a transformer is loaded, is measured.

Instead of alternating current meters, we have used a wall galvanometer with a cuprous oxide rectifier which is calibrated both as an ammeter and a voltmeter of the proper ranges in the same experiment. Students' results are usually correct to 1 percent through a range of 4–40 mh. This experiment, being presented near the end of the electrical work, reviews the preceding experiments on the structure of meters, on potential dividers, and on Ohm's law, and presents one new concept. In their first electrical experiment, the students have plotted a direct current-voltage curve for the rectifier unit, hence understand its rectifying properties.

Exp. 2. *Phase relations in an inductive circuit.* Until the cathode-ray oscilloscope became generally available, it was very difficult to present the concept of phase relations experimentally. Since the student is familiar with Lissajous' figures from mechanics, the basic principles of the oscilloscope are at his command. We used an RCA cathode-ray oscilloscope containing horizontal and vertical electrostatic deflecting plates with gain controls, and a linear time oscillator which may be switched to the horizontal plates without disturbing the external circuit.

First, the deflecting plates are connected across two noninductive resistances R and S (Fig. 1) and it is shown that R alone produces a vertical displacement and S alone produces a horizontal one. Together they produce a straight line which is the vector sum of the two. By switching the horizontal plates to the linear oscillator switch, set for 60 cycles, the wave-form is observed.

Next, an inductance X of ohmic resistance R' is substituted for R. Again, separately they produce straight lines, of length A along the vertical axis, and B along the horizontal axis. But now their vector sum is an ellipse whose equations are $y=A\sin(\theta+\varphi)$, $x=B\sin\theta$. By elementary trigonometry, when θ is eliminated from these equations, an equation of an ellipse results. In this equation, if $x=0$, $y=A\sin\varphi$; if $y=0$, $x=B\sin\varphi$. Hence, by measuring the x and y intercepts and the lengths A and B of each component when the other gain is zero, $\sin\varphi$ is obtainable, from which $\tan\varphi$ is secured. But $\tan\varphi=X/R'$, hence $L=X/2\pi n$ may be found. The resistance S is adjusted to be of the same

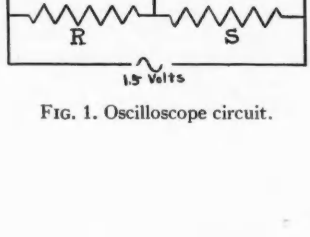

Fig. 1. Oscilloscope circuit.

FIG. 2. Induction and resistance.

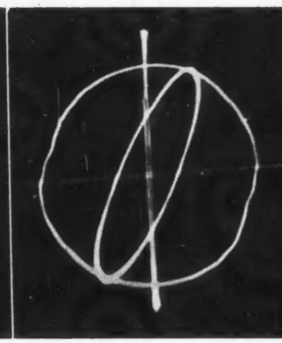

FIG. 3. Capacitance and resistance. $R=0$ and 4000 ohms; $S=2000$ ohms.

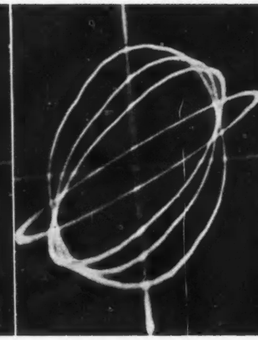

FIG. 4. The four ellipses are due to secondary loads of open circuit, 10, 4 and 1 ohm. $R=732$ ohms; $S=2000$ ohms.

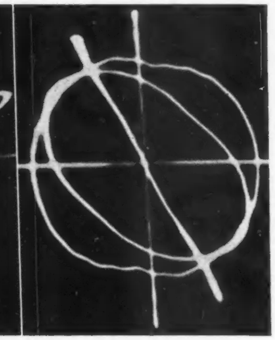

FIG. 5. Resonance. $C=0.425\,\mu f$; $R=2.732$ ohms; $S=3000$ ohms.

order of magnitude as the impedance X. Thus values of L over wide ranges may be determined.

Fig. 2 shows two Lissajous figures from a standard variable inductance. The axes were traced upon the plate by alternately reducing the x, then the y gain to zero. The ohmic resistance R' of the induction coil was 9.5 ohms, and the resistance S across the horizontal plates, 9.0 ohms. Sixty-cycle current was used throughout. Measurements of the intercepts and maximum x and y values give average values of $\sin\varphi=0.845$ and 0.355; and from the corresponding values of $\tan\varphi$, $X=15.2$ and 3.62 ohms, $L=41$ and 9.7 mh. These are centimeter-scale measurements and slide rule reductions, such as students employ.

For student use, measurements may be made directly upon the fluorescent figure. Since static charges affect the figure, it has been found advisable either to reflect the figure upon a cross-section screen by means of a sheet of plane glass, to mount a transparent cross section screen over the fluorescent screen which is observed through a reading telescope, or to use a cross section eyepiece in the telescope.

Fig. 3 was secured by replacing the inductance with a condenser. The gains were adjusted to give a nearly circular figure with pure capacitance. In this figure, the phase angle is 90°, but the addition of a resistance in series with the condenser will produce a smaller phase angle. Measurements on this ellipse give $\sin\varphi=0.553$, $\tan\varphi=X/4000=0.660$, $X=1/2\pi nC=2660$ ohms, $C=1.00\mu f$.

Fig. 4 demonstrates the decrease of primary inductance with increase of secondary load in a transformer. Having already made these measurements by the voltmeter-ammeter method and having observed (Fig. 2) the effect on the ellipse of decreasing the inductance, the student is now prepared to understand this as a demonstration. Measurements from the figure, of course, may also be made. In Fig. 4 they give 16, 3.0, 1.96, and 0.69h for the inductances. The largest value is difficult to measure because the impedance is large compared with the resistance. If it is desired to use this method for measuring such inductance, a known resistance of several thousand ohms is placed in series with it. The resulting ellipse of greater eccentricity will then yield more exact values and exhibit less distortion. This same inductance is shown in Fig. 5 with 2000 ohms in series. Calculations from this figure give $L=16$h. A case of resonance is shown in Fig. 5. The approximately circular figure is from a capacitance of $0.425\mu f$ against 3000 ohms. The line represents R, L, and C in series. Changing the capacitance in either direction spreads the line into an ellipse. Resonance is also affected by the resistance.

Distortions of the wave form are frequently encountered. Small ripples occur when the impedance is large compared to the resistance.

These are evident in Figs. 3, 4, and 5. The small ripples can be ignored in measurements. The presence of iron in an inductive circuit, however, sometimes introduces large distortion, which may be reduced with a series resistance.

Thus in two experiments the basic principles of self-inductance may be presented with relatively inexpensive and nonspecialized equipment.

A Mechanical Stroboscope

PAUL D. BALES AND EDGAR BLACKBURN
Department of Physics, Howard College, Birmingham, Alabama

A SIMPLE mechanical stroboscope suitable for viewing fan blades, tuning forks, vibrating strings, etc., is shown in Figs. 1 and 2. The light from an automobile headlight bulb is formed into a parallel beam by a small lens L_1 (from an old flashlight) of focal length approximately 2.8 cm. The bulb is operated from a small transformer. An 8-in. disk containing a $\frac{7}{8}$-in. hole interrupts the beam of light; masonite or pressed fiber-board $\frac{1}{8}$-in. in thickness is preferable to metal for the disk. The disk is balanced by a small bolt on the same side as the hole. After the light passes through the disk it is spread out by a diverging lens L_2 of focal length 6 cm, approximately, whose position may be adjusted to change the size of the beam.

The disk is rotated by a small shunt motor whose speed is controlled by changing the terminal voltage. The voltage supply used for this particular instrument is from a motor-generator set (Fig. 1), the output of which is adjusted by a series resistor in the shunt field. This resistor consists of two parts, one of 1000 ohms at 50-watt dissipation and one of 30 ohms which serves as a trimmer. If direct current is available from some other source, the voltage at the motor may be varied by a series resistor in the line. All the parts except the motor-generator set are mounted in a box which is painted black on the inside. The motor used gives speeds varying from 25 to 7000 rev./min. which may be read on the calibrated scale of the 1000-ohm resistor when the 30-ohm trimmer is cut out of the circuit.

Fig. 3 shows the complete circuit used.

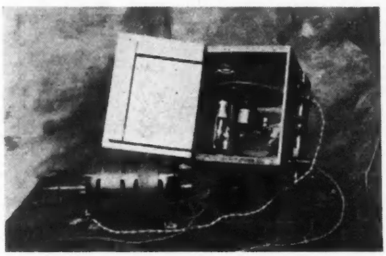

FIG. 1. Top view of stroboscope.

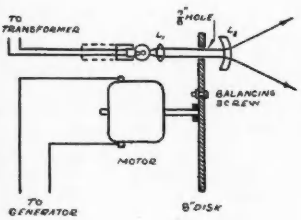

FIG. 2. Diagram of stroboscope.

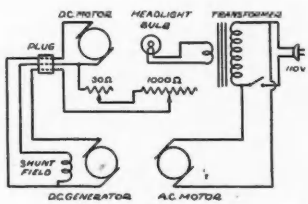

FIG. 3. Diagram of circuit.

Important Notice to Subscribers

BECAUSE of the large amount of worthy material submitted to us and a demand for more frequent publication of the journal, we are glad to announce that *The American Physics Teacher* will hereafter appear bi-monthly in February, April, June, August, October, and December.

—THE EDITOR

DISCUSSION AND CORRESPONDENCE

Magnetic Heat-Motor

AT the October meeting of the American Institute of Physics in New York City exhibit space was assigned to a number of industrial and academic institutions. In that of Bell Telephone Laboratories was an unnamed piece of apparatus, labeled only with a question mark. The attendant made no explanation nor did he vouchsafe agreement with any suggested explanations. This exhibit, which is shown in Fig. 1, puzzled many observers although some promptly volunteered the correct explanation.

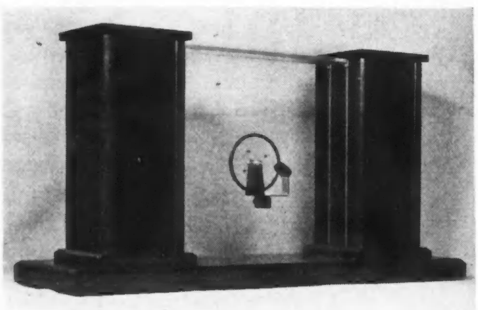

FIG. 1. Photograph of magnetic heat-motor.

Two parallel glass plates about 15 in. square were supported vertically by two wooden pillars. Bolted to one of the plates, and so supported by it, was a brass bracket which in turn supported an axle on which was mounted a thin transparent disk about 5 in. in diameter. The rim of the disk was apparently a thin metal tape. At one point the rim passed between what appeared to be the poles of a small horseshoe (actually a circular) magnet. A few ink marks on the transparent disk allowed observation of its continuous rotation.

Those who arrived at the correct solution concluded that there was concealed in one of the wooden pillars a source of infrared radiation which traveled along the space between the plates and fell upon the metal rim just above the permanent magnet. As the disk rotated successive portions of the tape passed through the field of the magnet into the position to receive the radiation. That this was the correct explanation appears from Fig. 2, which shows the apparatus before the dark glass panels were inserted.

The radiation heats the tape on one side of the magnet, reducing its permeability and so resulting in an unbalanced pull. This tends to draw the unheated portion of the tape into the gap between the pole pieces. The permeability of the new portion exposed to the radiation is then reduced; and so the disk continues to turn. Because the tape is thin and because the edge of the disk on which it rests is grooved to facilitate loss of heat, the effect of the radiation is rather sharply localized.

That iron loses its ferromagnetic properties when heated to redness has been known for centuries. The temperature at which this occurs is today known as the *Curie point* after P. Curie who investigated it. That a magnetic motor might be constructed on the basis of this phenomenon was proposed about fifty years ago by Edison. The idea, which appears to have no practical value, has reappeared in scientific literature several times since then. In a popular science magazine of twenty years, or so, ago a "perpetual motion" puzzle was described in which this principle was applied; the rim of the wheel was heated by an alcohol lamp and a concealed bar magnet was used for the attraction.

The present model has been made possible by the proper choice of materials. The rim consists of an alloy of 70-percent iron and 30-percent nickel which curiously enough has its maximum permeability at about room temperature and suffers appreciable losses as the temperature is either raised or lowered by a small amount. Very little heat is, therefore, required to produce a pronounced effect. The circular magnet is one of the strongest permanent magnets possible, a nickel-iron-aluminum alloy. Because of the properties of these magnetic materials the device will operate in the feeble heat radiation emitted by a small automobile head lamp when filtered for all but its infrared rays.

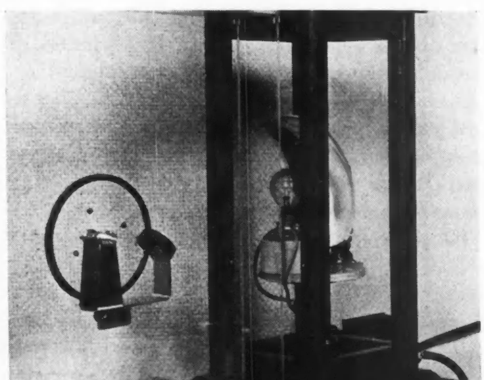

FIG. 2. Pillar with sides removed.

For lecture room demonstration, apparatus which disguises the operation is not required and the effect can readily be produced with simple apparatus provided that the proper tape is used in the construction.

JOHN MILLS

Bell Telephone Laboratories,
New York City

Another Substitute for Stop Watches

THE article on "A Simple Laboratory Timer" by Herschel Smith [Am. Phys. Teacher 4, 136 (1936)] prompts us to report on a different solution of the same problem. We have replaced a number of stop watches by ordinary synchronous electric clocks. The requirements are that the clock have a self-starting motor, a round dial and a second hand. Such clocks may be purchased for five dollars or less. A cord switch at the end of a short piece of cord is added. It is found that the clocks start without appreciable loss in time, but that they coast on from 0.1 to 0.5 sec. in indicated time after the circuit is opened. This correction seems to be constant for any one clock, and is easily observed. Since there is no reset device for the second hand it is necessary to read the time before and after each interval measured. In actual student use the clocks appear to be quite comparable with stop watches in accuracy. Some care in the selection of a quick-acting switch is advisable.

W. H. MICHENER

Department of Physics,
Carnegie Institute of Technology,
Pittsburgh, Pennsylvania.

Interdepartmental Cooperation in Related Fields

IN Westminister College we are trying to break down to some extent strict departmental lines, particularly in the work of the last two years. The aims are to encourage interdepartmental cooperation in related fields and to further stimulate the student body.

The physics department is cooperating by conducting the weekly Friday meeting of the course in *Thermodynamics* as an extended afternoon seminar to which the staff members and advanced students of other departments are invited. Members of the staffs of the biology, chemistry and mathematics departments and others have been attending and contributing to the discussions. Dr. John G. Moorhead, Associate Professor of Physics, is in charge of the course. The text used is Planck, supplemented by problems. Incidentally, the student is encouraged to use the German or French edition of the text, as well as Ogg's English translation, depending upon his language facility.

ALEX. C. BURR, *Dean*

Westminister College,
New Wilmington, Pennsylvania.

Demonstrations of the Edison Effect and the Rectifying Action of a Diode

WE have found it instructive to supplement the usual Edison-effect demonstration, consisting of a galvanometer or milliammeter in the plate circuit of a diode, with a simple gold leaf electroscope, to show clearly the nature of the emission. We use for this purpose a 200- or 300-w incandescent lamp into which a plate has been sealed. The lamp is well pumped, and the outside glass cleaned to minimize electrical leakage. The plate is connected to the electroscope as in Fig. 1. With the electroscope positively charged the leaves collapse immediately when the filament is lit. The difference in behavior with the electroscope negatively charged, clearly shows the negative nature of the emission from the filament.

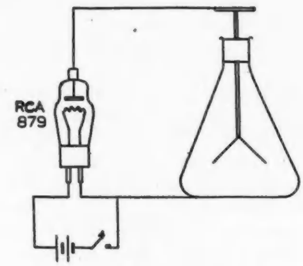

FIG. 1. Edison Effect.

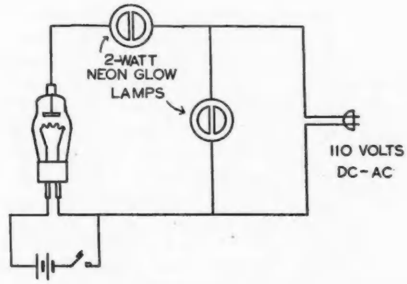

FIG. 2. Rectifying action of a diode.

The new RCA 879 half-wave rectifier furnishes a convenient, inexpensive substitute for a home-made diode. For large groups, the tube and electroscope may be shadow-projected on a ground glass screen by means of an auto lamp used as a "point" source.

To show the rectifying action of the diode, two 2-w neon glow lamps are connected as in Fig. 2. When the circuit is connected to a d.c. line and the polarity reversed, the neon lamp directly connected clearly shows the reversal of the polarity whereas the lamp in the plate circuit lights only with the proper polarity. On a.c. the rectifying action of the diode is clearly shown since both plates of the neon glow lamp light on a.c. but only one plate of the lamp in the plate circuit is lit.

It is also interesting to observe the persistence of electron emission from the filament, when the filament current is shut off. The heat capacity of the filament of the 879 tube is rather large and the plate current, as shown by the neon lamp, continues to flow for many seconds after the filament circuit is opened, dropping off visibly as the temperature falls.

SIMON SONKIN

City College,
College of the City
of New York.

Recent Publications

Survey Textbooks

The Physical World. Louis M. Heil, associate professor of electrical engineering and physics, Ohio University. 575 p., 426 fig., 36 tables, 14 × 21 cm. *Blakiston's*, $2.75. The author of this survey text for nonscience majors knows how to choose subject matter and how to present it in a style that is neither "popular" nor ingratiating. He knows something about selecting illustrations that really enhance the text. Moreover, his treatment shows realization of the idea that in any properly integrated survey of astronomy, physics, and chemistry, the fundamental principles of physics must be made the basis of the whole picture. Since these are features that do not appear together in any other survey textbook on physical science that has come to our notice, it is with real regret that we must take note of the occurrence of numerous loose statements, slips and poor use of terms. To make the alterations which are really needed would be a relatively simple task and the result might easily be an outstanding text for the purpose for which it is intended. The book work is good; the cloth binding is washable and, the publishers say, vermin proof.

First Year Laboratory Manuals

Experiments in Physics. Leonard Rose Ingersoll, professor of physics, University of Wisconsin, and Miles Jay Martin, associate professor of physics, Milwaukee Extension Center, University of Wisconsin. Ed. 4. 318 p., 117 fig., 14 × 20 cm. *McGraw-Hill*, $2.50. This manual has the reputation of having achieved a rather nice balance between directions for the student that are too specific and those that are too sketchy. The 82 experiments range from relatively simple ones to those that are somewhat exacting in character. In the present edition two new experiments appear, one on thermal conductivity,* the other on the earth inductor. Several of the illustrations have been revised and some errors have been corrected.

* A. L. Fitch, Am. Phys. Teacher **3**, 135 (1935).

Reference Books for the First Course

Cosmic Rays Thus Far. Harvey Brace Lemon, professor of physics, University of Chicago. 128 p., 22 fig., 14 × 22 cm. *Norton*, $2. A fascinating and authentic little volume for the general reader on the discovery of cosmic rays and the attempts which have been made to understand them, a subject which the author has been in a good position to follow for many years. Chichi Lasley made the decorative drawings and there is a brief foreword by A. H. Compton. The title of the book seems to be unusually appropriate.

The Science Masters' Book, Series II, Part I, Physics. Ed. by G. H. J. Adlam. 304 p., 217 fig., 14 × 22 cm. *John Murray*, 7s, 6d. A useful and interesting collection of 194 notes on all sorts of novel apparatus, inexpensive gadgets, ingenious variations of demonstration and laboratory experiments, arts, and tricks, selected from the *School Science Review* by the editor of that journal and a committee of the Science Masters Association (England). A sizable section is devoted to "Experiments suitable for receptions, speech days and general occasions." Every school laboratory should have a copy of this book and of *Series I, Part I*, which also costs 7s, 6d and contains 212 items of a similar nature and usefulness.

A Mathematician Explains. Mayme I. Logsdon, associate professor of mathematics, University of Chicago. Ed. 2. 189 p., 122 diagrams by Chichi Lasley, 17 × 23 cm. *Univ. of Chicago Press*, $1.50. The present edition of this Chicago "New Plan" text has an added chapter, entitled "Mathematics and Life," which outlines the importance of mathematical theories and methods in the various natural sciences and social studies. The book, like the other members of the "New Plan" series, is not intended to take the place of the texts used in the standard courses. Its purpose, for which it seems to be fitted very well, is to provide a text for a brief orientation course or a reading reference for other elementary courses. Surely the time will come when material of the methodological, historical and cultural types used in this book will find its way more generally into even the standard elementary textbooks. The object should be not to soften such courses but to enrich them so that the student will gain some appreciation of the meaning, the beauty and the power of mathematics, and of the role that men play in creating it.

Electricity. W. L. Bragg, Langworthy professor of physics, Victoria University of Manchester. 288 p., 140 fig., 15 × 22 cm. *Macmillan*, $4. The basis of this book is the six lectures on electricity given by the author in 1934 as the 109th of the famous Christmas series for young people at the Royal Institution. Professor Bragg believes that the average person experiences a peculiar difficulty in grasping the ideas of electricity and magnetism, and he anticipated this difficulty in planning and working out the details of the present lectures. The fundamental ideas of electricity are presented in as simple a way as possible and the account is rendered interesting to the general reader by showing how these ideas are illustrated in everyday apparatus—motors, dynamos, power stations, and communication equipment. The style is clear and enjoyable, even in the descriptions of rather intricate devices. The photographs and diagrams are good. In the present edition, certain phrases have been changed to conform to American usage.

Intermediate Textbooks and References

Electronics and Electron Tubes. E. D. McArthur, Vacuum Tube Engineering Department, General Electric Co. 181 p., 89 fig., 15 × 23 cm. *Wiley*, $2.50. The elementary treatment afforded by this book is suitable as a first reference for the intermediate student or serious beginner who is interested in electron tubes and their

applications. Mathematics is used sparingly, in the statement of a few formulas. Fundamental principles are dealt with at some length and there are special chapters on two-electrode tubes, control of electron currents, triode and multi-grid-tube applications, gas- or vapor-filled tubes, tube construction, etc. Much of the material appeared originally in serial form in the *General Electric Review*.

Advanced Laboratory Practice in Electricity and Magnetism. Earle Melvin Terry, late professor of physics, University of Wisconsin. Rev. by Hugo Bernard Wahlin, professor of physics, University of Wisconsin. Ed. 3. 332 p., 175 fig., 15 × 23 cm. *McGraw-Hill*, \$3. The third edition of this widely used and successful manual contains two new experiments—on the electronic charge and on the thermionic work function of a metal. The chapter on electron tubes and two of the experiments have been partially rewritten. As in the first edition (1922), the usual experiments in electrical measurements are supplemented by exercises in radioactivity, thermionics, and the discharge of electricity in gases. The various sets of experiments are prefaced by clear and relatively simple discussions of theory.

An Elementary Survey of Modern Physics. Gordon Ferrie Hull, professor of physics, Dartmouth College. 481 p., 232 fig., 17 tables. *Macmillan*, \$4.50. In this textbook for a survey course in modern physics the author has not made simply a collection of material from various sources, but has developed a presentation that is very much his own and into which he evidently has put considerable thought as to the simplest and most effective ways to present the various topics. Because the book is in this sense rather original, opinions about it obviously are likely to differ more widely than in the case of a textbook that follows the usual course of departing only slightly from other books of its kind. Many experienced teachers doubtless will have good reasons for objecting to the large amount of material which the book attempts to cover, and to the brevity with which many of even the most difficult topics are treated or dismissed. Other teachers, however, will recognize the skill with which the author has condensed or simplified many of the treatments and will welcome the opportunity afforded by the somewhat encyclopedic-like survey to select those topics best adapted to the aims and interests of a particular course or individual; topics thus selected for emphasis can of course be developed to any desired degree of understanding with the aid of lectures and of reading assignments to original papers and other books. The book is up-to-date and includes material on electron tubes, Fermi-Dirac statistics and thermionic phenomena, super-conductivity, the Raman effect, cosmic rays, slow neutrons, and artificial radioactivity. Emphasis is placed on the atomic idea, on properties of ultimate particles, on photons, and on some of the many interactions of matter and radiation. It is shown that we have been driven to the quantum view by the compulsion of experimental evidence, and that relativity theory has played little part in this experimental work. In a preface "To Teachers," the author urges the use of as many demonstration-experiments as possible . . . "the glass spheres in mercury vapor, the Brownian movement, the oil drop experiment, magnetic and electric deflection of electron streams, x-rays, even the inspection of the x-ray plant in a well-equipped hospital, electron tubes, thyratrons, Geiger counters and cosmic rays." The author found, for example, that students were interested in watching him blow and mount extremely fine quartz fibers. He sees "no danger that these excursions into the experimental realm will detract from the vigorous pursuit of the arguments . . . ." We are inclined to go further and say that the great danger in intermediate courses is a tendency to neglect demonstrations and closely integrated laboratory work. The stress which the present author places on the experimental point of view should be commended, for he does not allow it to degenerate into bare recitals of facts or, in the words of a lay author (Marthe Bibesco), into "so much discussion of nature that it is no longer necessary to go and look at it." Certainly few of us want any student to get the idea recently expressed by a professor of mathematics, that physics "Was [sic] an observational science, ultimately became 'the theory of certain differential operators,' and at present may be said to have become the theory of certain linear operators." Perhaps the single most important idea that anyone can learn about physics is that its essential strength lies in a continual resort to experiment, and that it is only through the constant interplay of experiment and theory that the science has obtained its enormous successes.

Advanced Textbooks and References

An Introduction to Atomic Physics. John Thomson, lecturer in natural philosophy, University of Glasgow. 273 p., 40 fig. and plates, 14 × 22 cm. *Van Nostrand*, \$3.50. The aim of this book is to provide students with a concise, logical account of the experimental basis of atomic physics, the theory of atomic structure, and of molecular, atomic and nuclear radiations. The discussion is more critical and mature, and more attention is given to methodological implications, than is usual in a book of this type. It should provide good collateral reading for the more able students in an upper-division survey course in modern physics.

Thermodynamic Properties of Steam. Joseph H. Keenan, associate professor of mechanical engineering, and Frederick G. Keyes, chairman of the department of chemistry, Massachusetts Institute of Technology. 89 p., 10 fig., 11 tables, 19 × 26 cm. *Wiley*, \$2.75. These tables are the successor to the *Keenan Steam Tables and Mollier Diagram*, which appeared some six years ago. They are computed from entirely new formulations of the properties of water and now include data for the liquid and solid phases. Data on the viscosity, thermal conductivity, compressed liquid properties, etc., are included. Data sources and the methods used to prepare the tables are given. The authors point out that these tables may be expected to have a high degree of permanence, for the data on water are now considerably increased by the practical completion of various investigations which have been in progress.

The Quantum Theory of Radiation. W. Heitler. 261 p., 26 fig., 15 × 24 cm. *Oxford Univ. Press*, $6. This important book should go a long way toward filling the need for a treatment of the theory of radiation from a uniform point of view. After an introductory chapter on the Maxwell-Lorentz theory, the author gives a formal, clear and concise development of the quantum theory, "in the simplest form of general validity," that of Fermi and Dirac. Special consideration is given to processes occurring at high energies, such as Compton scattering and positron formation, and to the problem of the reaction of the field on the electron. Questions relevant to atomic structure rather than the theory of radiation are not given detailed consideration, nor is Planck's law discussed at length, since it is adequately treated elsewhere. Some errors occur, part of them apparently being typographical in character. The book is one of the *International Series of Monographs on Physics*, edited by R. H. Fowler and P. Kapitza.

Principles of Electric and Magnetic Measurements. P. Vigoureux and C. E. Webb, National Physical Laboratory. 403 p., 197 fig., 14 × 22 cm. *Prentice-Hall*, $5. The comprehensive and relatively advanced treatment of electric and magnetic measurements provided by this book should make it exceedingly useful as a reference for the serious student in the advanced or research laboratory. Considerable space is given to a much larger variety of standard measurements than one ordinarily finds in a text of this kind, and there are also chapters on many of the fundamental measurements in electronics and atomic physics. Emphasis is placed on the fundamental principles of accurate measurements and on difficult technics, rather than on theoretical derivations. The methods and instruments described are strictly modern. Use is made of the new scheme of units based on the kilogram-meter-second system which unifies the electromagnetic and practical units. To facilitate reading, the authors have deliberately refrained from quoting many names in the text and have omitted any references to papers and other textbooks. This is the first book in the new Prentice-Hall Physics Series under the general editorship of E. U. Condon.

Biological Effects of Radiation. Ed. by Benjamin M. Duggar, professor of plant physiology and applied botany, University of Wisconsin. 2 vol., 1353 p., 169 fig., 121 tables, 15 × 23 cm. *McGraw-Hill*, $12. This important collective contribution on the present status of knowledge in various aspects of radiation in relation to biological problems was prepared under the auspices of the Committee on Radiation, Division of Biology and Agriculture, National Research Council. Its publication was made possible through funds supplied by several foundations. On the editorial board were four biologists, a chemist, and a physicist (G. Failla, Memorial Hospital, New York City). The 43 papers comprising the survey were prepared by specialists in the fields treated. For example, Karl K. Darrow wrote on "Photons and electrons;" Lauriston S. Taylor, on "Measurements of x-rays and radium;" G. Failla, on "Ionization and its bearing on the biological effects of radiation." Each paper gives an extensive list of references, there being about 4000 references in all. Subjects excluded from the survey include: purely clinical and therapeutic phases of applied radiology; practical considerations relating to plant production; applied phases of absorption spectroscopy; emission spectral analyses of tissues; and radiation problems relating to vision in higher animals and man.

Methodology and Philosophy of Science

Philosophy and the Concepts of Modern Science. Oliver L. Reiser, associate professor of philosophy, University of Pittsburgh. 340 p., 15 × 22 cm. *Macmillan*, $3.50. Although more than half of this book deals with philosophy and the physical sciences, the treatment is not one that is likely to interest or to inspire the confidence of the physicist. The author is often uncritical in his use of the conclusions of the sciences.

The Philosophy of Physics. Max Planck, professor of theoretical physics, University of Berlin. Tr. by W. H. Johnston. 128 p., 14 × 21 cm. *Norton*, $2. In the first two of these four essays, the discoverer of the quantum again deals with the problem of causality and with his refusal to renunciate the doctrine of determinism. The doctrine can be preserved, he explains, by modifying the principle of causality. The third essay, in which the origins and characteristics of scientific ideas are traced, contains an interesting digression on the teaching of the sciences in schools (p. 99f). After reminding us that the public is favorably impressed if the curriculum of the intermediate school contains modern problems of scientific investigation, Professor Planck suggests that such a practice is exceedingly dangerous, for these problems cannot possibly be dealt with thoroughly and the consequence may easily be a certain intellectual superficiality and empty pride in knowledge. He would consider it extremely dangerous if the schools were to deal with relativity or quantum theory, or were to treat a question like that of the universal validity of conservation of energy as debatable before students who cannot have properly grasped the meaning of the principle involved, much less its potential scope. In the last essay, on "Science and Faith," the author seeks a philosophy of the world to be applied to the problem of life, based on the faith of the scientist in the rational ordering of the world. The position is taken that it is untenable to hold that physics, with its restricted universe of discourse, is unable to contribute materially to such a general philosophy.

Miscellaneous

General Chemistry. Horace G. Deming, professor of chemistry, University of Nebraska. Ed. 4. 789 p., 169 fig., 14 × 22 cm. *Wiley*, $3.50. A new edition, much revised. Industrial applications of fundamental principles are emphasized. Many references are given to articles in both technical and semi-popular periodicals.

Proceedings of the American Association of Physics Teachers

The Atlantic City Meeting, December 29–31, 1936

THE sixth annual meeting of the American Association of Physics Teachers was held at the Chalfonte Hotel, Atlantic City, New Jersey, on December 29–31, 1936. The presiding officer was D. L. Webster, President of the Association.

At a joint session with Section B, A.A.A.S., and the American Physical Society the following invited papers were heard:

Electron Impacts in Gases. John T. Tate, *University of Minnesota.*

Multiple Ionization of Atoms. F. K. Richtmyer, *Cornell University.*

At the dinner held jointly with the American Physical Society at the Chalfonte Hotel, F. K. Richtmyer presided. In a ceremony described elsewhere in this issue, D. L. Webster and Frederic Palmer, Jr., announced the presentation, posthumously, to William Suddards Franklin, of the first A.A.P.T. Award for Notable Contributions to the Teaching of Physics.

Contributed Papers and Abstracts

Reports were presented by the following committees: Examination for Profession of Physicist; Ideal Undergraduate Curriculum; Membership; Physics for Premedical Students; Preparation in Mathematics; Manual of Demonstration Experiments; Training of Physicists for Industry; Units and Dimensions. These reports will appear in forthcoming issues of the journal.

Three sessions were devoted to the following contributed papers. Abstracts are omitted in the cases of papers scheduled for early publication in the journal and papers read by title.

1. Acoustical, Mechanical and Electrical Analogies. R. B. Abbott and C. Fry, *Purdue University.*

2. The Mass of Energy. A. Marcus, *College of the City of New York.*

3. The Photoelectric Determination of *h* in the Undergraduate Laboratory. Winthrop R. Wright, *Swarthmore College.*

4. An Experimental Film on Wave Motion. Robert L. Petry, *University of the South.*—The use of motion pictures in demonstrating phenomena of wave motion has been studied and amateur methods have been used to animate the drawings generally employed to explain these phenomena. One group of studies begins with a stationary transverse wave shown as the resultant of two transverse waves moving in opposite directions, then represents a sound wave, and finally shows the character of a stationary longitudinal wave set up in a pipe. A second group shows a cross section of a spherical wave front and of an ellipsoidal wave front set up in a doubly refracting crystal; illustrates Huygens' principle as applied to circular wavelets; and represents the application of this principle to elliptical wavelets in a doubly refracting crystal to show why bending of a ray may be caused even when the incident ray is perpendicular to the surface of the crystal. Color is used in some of the films in order to distinguish between components.

5. The Place of Photography in the Physics Curriculum. Paul E. Boucher, *Colorado College.*

6. Undergraduate Projects in Supersonics. J. C. Hubbard, *The Johns Hopkins University.*

7. Demonstration of Three Pieces of Lecture Room Apparatus. Richard M. Sutton, *Haverford College.*—(1) *Dynamic earth-moon system.* A nonscale model of the earth-moon system is made by attaching a 15-cm globe of the earth to a 6-cm sphere (moon) by a 60-cm brass tube. Dry cells placed inside the "earth" supply energy to small lights located on each sphere and at the center of mass of the system. When the model is suspended from a 75-cm wire connected at the middle of the brass tube, 15-cm from the center of mass, and is rotated by a hand drill, the spheres take up a nearly horizontal plane of rotation about an axis through the center of mass. (2) *Acceleration car.* A liquid manometer [Am. Phys. Teacher **3**, 77 (1935)] has been given a multiplying factor [Phys. Rev. **49**, 414 (1936)] to make it a direct-reading accelerometer of moderate size suitable for lecture table and laboratory experiments. The meter utilizes the inertia of a horizontal mercury column to produce changes in level in a vertical water manometer, changes which are directly observable and proportional to acceleration. When mounted on a car moving on the lecture table, the manometer measures accelerations of the order of 1 ft./sec.^{2} unmistakably. (3) *Free-fall paradox.* The part played by "center of oscillation" in a body which undergoes angular acceleration is emphasized by a simple gadget [Science **84**, 246 (1936)] consisting of a ball and stick. The stick is pivoted at one end and the other end is allowed to fall by the removal of a prop which holds it at 30° from the horizontal. The ball, which rests upon the upper end of the stick, falls freely with the acceleration of gravity, but the end of the stick falls with still larger acceleration. The ball drops into a tall cup carried down by the falling stick.

8. Two Fundamental Experiments in Magnetism and Electricity. R. J. Stephenson, *University of Chicago.*

9. Galileo's Hour-Glass Experiment. John J. Heilemann, *University of Pennsylvania.* (By title.)

10. The Incandescent Lamp Resistance Stabilizing Network. Joseph Razek, *University of Pennsylvania.*

11. A Low Cost Spark-Timer with Wide Frequency Range. Everett F. Cox and Paul R. Gleason, *Colgate University.*—A spark-timer which can be constructed in a

moderately well-equipped machine shop consists essentially of a synchronous motor connected by nonmetallic spur gears to a Ford V-8 coil and distributor. This spark-timer is superior to available commercial forms in that even with a one-to-one coupling to the motor the eight distributor points furnish a wide possibility of multiple time intervals, and with spur gears this range is greatly increased. Independent high voltage outlets for as many as eight spark-consuming pieces, such as free-fall apparatus in duplicate, moment of inertia disks, etc., give added advantage.

12. A Visual Sonometer for Student Use. Carl E. Howe *Oberlin College.*

13. An Artificial Artery. Noel C. Little, *Bowdoin College.*

14. The Status of Curriculums in Applied Physics. Homer L. Dodge, *University of Oklahoma.* (By title.)

15. A Principle of Consistency and a Concept of the Dielectric Constant. A. G. Worthing, *University of Pittsburgh.*

16. A Proposal for a Comprehensive Examination in Physics at the Baccalaureate Level. C. J. Lapp, *University of Iowa.*

17. Problems. T. D. Cope, *University of Pennsylvania.* (By title.)

18. A Study of Able Students. C. J. Lapp, *University of Iowa.* (By title.)

19. On the Lack of Logic in the Textbooks and Literature of Physics. Enos E. Witmer, *University of Pennsylvania.*—This is not a discussion of the logical and philosophical foundations of physics, but of the logical flaws in terminology and in the manner of presentation. Some of these flaws are universal, others are limited to certain writers. Some of the logical principles violated are:

(1) No word or symbol shall be used with more than one meaning (Examples of violation: induction, polarization); (2) No more fundamental principles, postulates, or laws shall be stated than are necessary (Example of violation: Newton's laws of motion);

(3) All the assumptions and postulates used shall be stated.

20. Mathematical Requirements for the First Courses in General College Physics. Karl F. Oerlein, *State Teachers College*, Indiana, Pa.—This study was suggested by the Chairman of the A.A.P.T. committee on "Student preparation in mathematics and college requirements in mathematics for the general course in physics." It was confined to the 273 institutions on the approved list of the Association of American Universities for 1933–34. A course in general college physics was considered a *first* course if it could be taken without previous college physics, if it included the usual subjects—mechanics, heat, light, electricity, magnetism, and sound (sometimes omitted)—and if college credit was allowed for it. The study consisted of three parts: (1) *An analysis of the minimum mathematics required for admission to the institutions.* The data were obtained from the official college catalogs. From 264 institutions, 330 minimum entrance specifications in mathematics were analyzed. They extended from no requirement to 4 units. The analysis showed a bi-modal distribution. The modal values occurred at 2 units for the Arts group and at 3 units for the Engineering group. (2) *An analysis of the mathematics required in addition to the entrance mathematics for registration in the first courses in physics.* The responses to a printed form sent to the departments of physics supplied the data. Reliable data for 351 courses in 211 institutions were obtained: 48.1 percent of the courses stated no additional prerequisite; 24.5 percent required trigonometry; 12.3 percent required analytics; 7.4 percent required calculus as corequisite. (3) *An analysis of the mathematics used in laboratory manuals prepared for local use.* Over 3000 experiments in 72 local manuals from 61 institutions supplied the data. There were revealed, among other things, the following: 52.8 percent of the manuals included a mathematical introduction; algebra was extensively used; one year of plane geometry in secondary school covers all the relationships found, for solid geometry is little used; very little trigonometry beyond the use of sine, cosine and tangent was found; graphs are used extensively and, in the more difficult manuals, the rudiments of the analytical treatment of the straight line and of the rectangular hyperbola are found; calculus is little used even in the most difficult manuals for engineering students. This analysis serves as a basis for an evaluation of the adequacy of the mathematics required for admission to the courses. The complete study contains 55 tables and figures, and lists of the mathematical items and terms found in the manuals.

21. Scholastic Aptitude Test Scores and College Grades in Mathematics and Science. M. Richard Dickter, *University of Pennsylvania.*—A study was made of the relationship between scores on the verbal and mathematical sections of the *Scholastic Aptitude Test* of the College Entrance Examination Board and marks in first-year mathematics, chemistry, and physics at the University of Pennsylvania during the years 1930–36. A total of 9251 marks were studied, involving 2466 students and 16 courses. Separate coefficients of correlation were calculated by the Pearson product-moment method for each year and for the entire period between scores on each section of the *Scholastic Aptitude Test* and marks in each of the courses. The results obtained are: (1) The correlations on the mathematical section are higher than those on the verbal section for every course, when considering results over the entire 6-yr. period; the same trend is apparent in the correlations for each of the years. (2) The correlations on the mathematical section are all above 0.4, with few exceptions. (3) The mathematical section is strongest in the case of college algebra, being close to 0.6, and weakest in the case of qualitative analysis, being just above 0.3. (4) The relationship between the verbal section and achievement in chemistry and mathematics is low, the coefficients remaining in the neighborhood of 0.1 or 0.2. (5) The verbal section makes its best showing, in comparison to the mathematical section, in the physics courses, the coefficients

ranging between 0.3 and 0.4. The relatively high correlations of the verbal section in physics may perhaps be explained by the fact that success in physics involves not only mathematical ability, but also the ability to read and understand abstract material, a type of thinking that the verbal section is designed to measure. It seems advisable, therefore, in the case of physics, to use the verbal section in conjunction with a mathematical section. (6) Since we are dealing with a single instrument and are on the college level, where the student personnel is more homogeneous than on the secondary level, the fact that the correlations for the mathematical section are almost all above 0.4 indicates a considerable positive relation between the scores made by students on the mathematical section of the *Scholastic Aptitude Test* at the time of entering the University and their future academic success in the fields of chemistry, mathematics, and physics. (7) The results of this study indicate the continued need for a mathematical section in the *Scholastic Aptitude Test* for mathematics and science.

22. Why Wait for the Calculus Notation? W. Irwin Thompson, *Los Angeles Junior College.* (By title.)

23. Aims and Methods in the Introductory Laboratory. V. E. Eaton, *Wesleyan University.*—Administrative officers are impressed by the fact that laboratory instruction is expensive. If we, who are convinced of its great importance, are to justify this expense we must be able to make a convincing statement of our aims and show how these aims are accomplished best by laboratory methods. The fundamental aim of an introductory laboratory course is not to train technicians, nor to "hammer home" ideas presented in the textbook, but to train the student to discriminate between pertinent and irrelevant material and to organize this material to answer the problem which he wants to solve. If this aim is to be accomplished each experiment must involve, for the student, an element of research; he should not know the answer before starting the experiment but should want to know it. He should not be asked to test a law that many generations of students have always found to be true. The directions should not be too complete. All the pitfalls should not be anticipated. The experiment should not be easy but should be a real challenge; if the student needs help he should always be required first to state his question precisely. In each experiment the student should make a critical study of the sources of error. Rather difficult extensions of the experiment should be suggested as a further challenge to the better students; these should be optional and should not be done for extra credit. A student profits most by an experiment in which he is interested. To maintain interest the apparatus must merit respect, there should be variety in the course, and the student should feel that what he is doing is very much worthwhile. Experiments are described to illustrate some of these rules.

24. Evaluation in Physical Sciences. L. M. Heil, *Ohio State University.*

25. The Place of Physics in a College Curriculum. J. G. Black, *Morehead State Teachers College.*—This paper raises the following questions: (1) How can physics complete with the many "soft" courses now in the curriculum? (2) How can we expect a student to enroll for a five-hour physics course requiring problems and laboratory reports when he can get an "A" grade much more easily in some other course? (3) Does physics "train the mind" more than does a course in cooking, sewing, or physical education? (4) If we adopt the point of view that a subject should be of immediate use in the social life of the student, how much of physics will be of such use? (5) Does the removal of mathematics and foreign languages from the secondary school graduation requirements indicate a softening in the secondary school? What will this mean for physics teaching? (6) How can college graduates who have taken increasingly soft courses meet increasingly difficult world problems? (7) If secondary school teachers study history, English, political science and education, what are they prepared to teach? (8) If experiments prove that the library is a better place in which to study physics than is the laboratory, how many laboratories will we need? (9) If two regular five-hour physics courses are compressed into an entertaining three-hour lecture course in cultural physics how many hours will thus be saved and what will be done with these hours? (10) If physics instruction is weakened, will science and engineering in general be weakened? In what sense does the future of civilization rest on the science of physics? (11) How may the vacant seats in the physics class rooms of the colleges be filled with interested, intelligent students?

26. A Survey of the Enrollment of Women in First Courses in Biology, Chemistry, and Physics. John B. Daffin, *Mary Baldwin College.* (By title.)

27. The Prenatal Existence of the Reflecting Telescope. L. W. Taylor, *Oberlin College.*—The reflecting telescope in its present form dates from the seventeenth century. There is some indication, however, that concave mirrors were in use as telescope objectives much before this time. There is no evidence that magnifying glasses ("eyepieces") were used to view the images formed by these objectives, the images apparently being observed with the unaided eye. This notwithstanding the fact that the properties of converging lenses used as magnifiers were known and a few such lenses made and used as early as the thirteenth century. Evidence is reviewed and critically evaluated that the thirteenth-century Friar, Roger Bacon, was one of the first to use concave mirrors in this way. Extracts from his own writings are quoted, describing the construction, at great labor and expense, of several such mirrors and telling what he did with them. Corroborative evidence from writings of his contemporaries seems nonexistent, but later writers recount the Oxford traditions as to the use which was made of Bacon's mirrors. Some of the accounts contain obvious exaggerations, mostly in the form of the imputation of magical powers, an interpretation which was natural for those times and for which allowance may properly be made without necessitating a complete rejection. One military commentator of the sixteenth century tells of successful attempts to make and use similar instruments in surveying and military reconnaissance and

states that the directions for making them came from an old book of Bacon's experiments. None of the evidence can be considered as more than mildly indicative. But the convergency of six lines of such evidence, quoted from independent sources, suggests that, though the full fledged reflecting telescope probably did not appear before the seventeenth century, its rudimentary predecessor has quite possibly not received the attention that it merits.

28. An Inertia Balance for the Lecture Room. William Schriever, *University of Oklahoma*. (By title.)

Report of the Secretary

The executive committee held four meetings at Atlantic City. Members present were D. L. Webster, J. G. Black, T. D. Cope, P. E. Klopsteg, F. Palmer, Jr., F. K. Richtmyer, D. Roller, R. J. Seeger, L. W. Taylor, W. S. Webb and A. G. Worthing.

Final arrangements were made for the half-day's program which the Association has been invited to sponsor on February 20 at the Durham-Chapel Hill meeting of the American Physical Society.

A petition for the organization of a regional chapter of the Association in the District of Columbia was approved; R. J. Seeger was appointed representative of the chapter on the executive committee. F. Palmer, Jr., was reelected representative of the Association on the governing board of the American Institute of Physics for a period of three years. Upon the recommendation of the Editor, the following were appointed associate editors of *The American Physics Teacher* for a period of three years: Carl Anderson, California Institute of Technology; Gladys Anslow, Smith College; E. U. Condon, Princeton University; Alpheus Smith, Ohio State University; F. W. Warburton, University of Kentucky.

Approval was given to the appointment of a special committee on Association finances and a committee on physical terminology, symbols and abbreviations. The President was authorized to communicate with the Society for the Promotion of Engineering Education with regard to the establishment of a joint committee on physics for engineers.

It was voted that contributed papers be limited to 10 minutes at all future meetings.

The Annual Business Meeting. The annual business meeting was held at 11:30 A.M., December 31, in the Roberts Room, Chalfonte Hotel. President Webster presided. The minutes of the business meeting of 1935 and the report of the treasurer for 1936 were read and approved. The results of the election of officers for 1937 were announced as follows:

President......F. K. Richtmyer, *Cornell University*
Vice President .H. B. Lemon, *University of Chicago*
Secretary......T. D. Cope, *University of Pennsylvania*
Treasurer.....P. E. Klopsteg, *Central Scientific Company*
Members of the Executive Committee: F. A. Saunders, *Harvard University;* A. W. Smith, *Ohio State University.*

On the question of amending Article VI of the constitution the result was for the affirmative.

The following recommendations were presented to the Association and were passed unanimously:

(1) That *The American Physics Teacher* hereafter be issued bi-monthly instead of quarterly;

(2) That the dues for 1937 remain at $3.00, but that for 1938 and thereafter they be made $5.00;

(3) That in 1937 the treasurer continue to accept annual dues of $7.50 and $15.00 from *Contributors* and *Sustainers*, respectively;

(4) That in 1938 and thereafter nonmember subscriptions to *The American Physics Teacher* be made $6.00.

A motion was made and, after much discussion, prevailed that in future elections of officers the names of two nominees for Vice President be placed on the ballot.

WILLIAM S. WEBB, *Secretary*

Annual Report of the Treasurer

Balance brought forward from Dec. 14, 1935		$1729.56
CASH RECEIVED		
Dues received[1]	$2298.00	
Donations	612.25	
400 paid 5¢ exchange charge	21.49	
Total Cash Received	$2931.74	
Total deposited from 12/15/35 to 12/15/36		2931.74
Total cash available		$4661.30
DISBURSEMENTS		
Stationery and supplies	$ 277.93	
Postage	138.21	
Secretary, Editor's office	126.00	
Editor's traveling expense	29.70	
Payments to American Institute of Physics	2801.49	
Miscellaneous expenses	30.50	
Service, exchange and discount charges, 11/1/35 to 12/15/36	24.47	
Total disbursed		3428.30
Balance on Hand,[2] Dec. 15, 1936		$1233.00

PAUL E. KLOPSTEG, *Treasurer*

I have audited the books of account and records of Dr. P. E. Klopsteg, Treasurer of the American Association of Physics Teachers, for the year ended December 15, 1936, and hereby certify that the foregoing statement of receipts and disbursements correctly reflects the information contained in the books of account. Receipts during the year were satisfactorily reconciled with the deposits as shown on the bank statements and all disbursements have been satisfactorily supported by vouchers or other documentary evidence.

WILLIAM J. LUBY, *C. P. A.*

[1] On Dec. 15 there were 792 members in good standing.
[2] A balance of approximately $1050 is due the American Institute of Physics for the publication of *The American Physics Teacher* during 1936.